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GEOLOGY OF CUBA[1]

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ABSTRACT

Cuba is regarded as an important though untested oil reserve. A large portion is underlain by a column of conformable unmetamorphosed Jurassic, Cretaceous, and Tertiary sediments. These include limestones with lesser portions of shale, sandstone, and conglomerate. The surface formations apparently reflect the structure of those which lie at greater depths. Adequate source material, reservoir beds, and structure for the formation and accumulation of petroleum are present. In several instances large oil accumulations have been dissipated by surface evaporation through post-Tertiary fissures. It appears that several of the large unfissured and untested anticlines may contain equally important intact and exploitable accumulations.

Though serpentine occurs in large areas, most of it is of late Tertiary intrusion, occurring, almost entirely, as dikes and surface flows and not as masses below folds or a material component of the pre-Jurassic basement. Its only relation to petroleum occurrences is that in certain cases both serpentine and oil have escaped from their respective reservoirs to the surface through the same late Tertiary fissures.

INTRODUCTION

Cuba is one of the few large untested possibly oil-producing areas that are sufficiently near American markets to deserve the consideration of operators who are interested in reserves that can be obtained in large tracts, on reasonable terms, and without drilling obligations.

The geology of the island, though complicated by the lithologic similarity between formations of different ages, can be satisfactorily detailed if a reasonable amount of time is allowed. For such work some knowledge of micropaleontology and tectonic principles is indispensable.

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A hurried "birds-eye view" of the island is generally a waste of time and money, which leaves the geologist bewildered and inclined to echo the unsound premises and pessimistic conclusions published many years ago before the development of micropaleontology.

Cuba is situated adjacent to the southern portion of the Atlantic seaboard. It has excellent roads, railroads, and shipping facilities. Cities and towns having good hotel facilities are situated at frequent intervals. Fuel and water are available at most points. Excellent skilled and unskilled labor is plentiful. The climate is subtropical. The Cuban Government claims that the island has the lowest death rate in the world. Geologic and geophysical field work and drilling operations there should be no more costly than those conducted in the United States.

Mountainous regions in the eastern, the central, and the western portions of the island occupy approximately one-fifth of its area. The remainder is prairie and plain of comparatively low elevation, which, however, in many places exhibits sharp relief.

There is a line of low hills extending with comparatively few interruptions along most of the northern coast, and another which extends through the east-central portion of Havana Province into western Matanzas Province. Approximately one-third of the island is in cultivation.

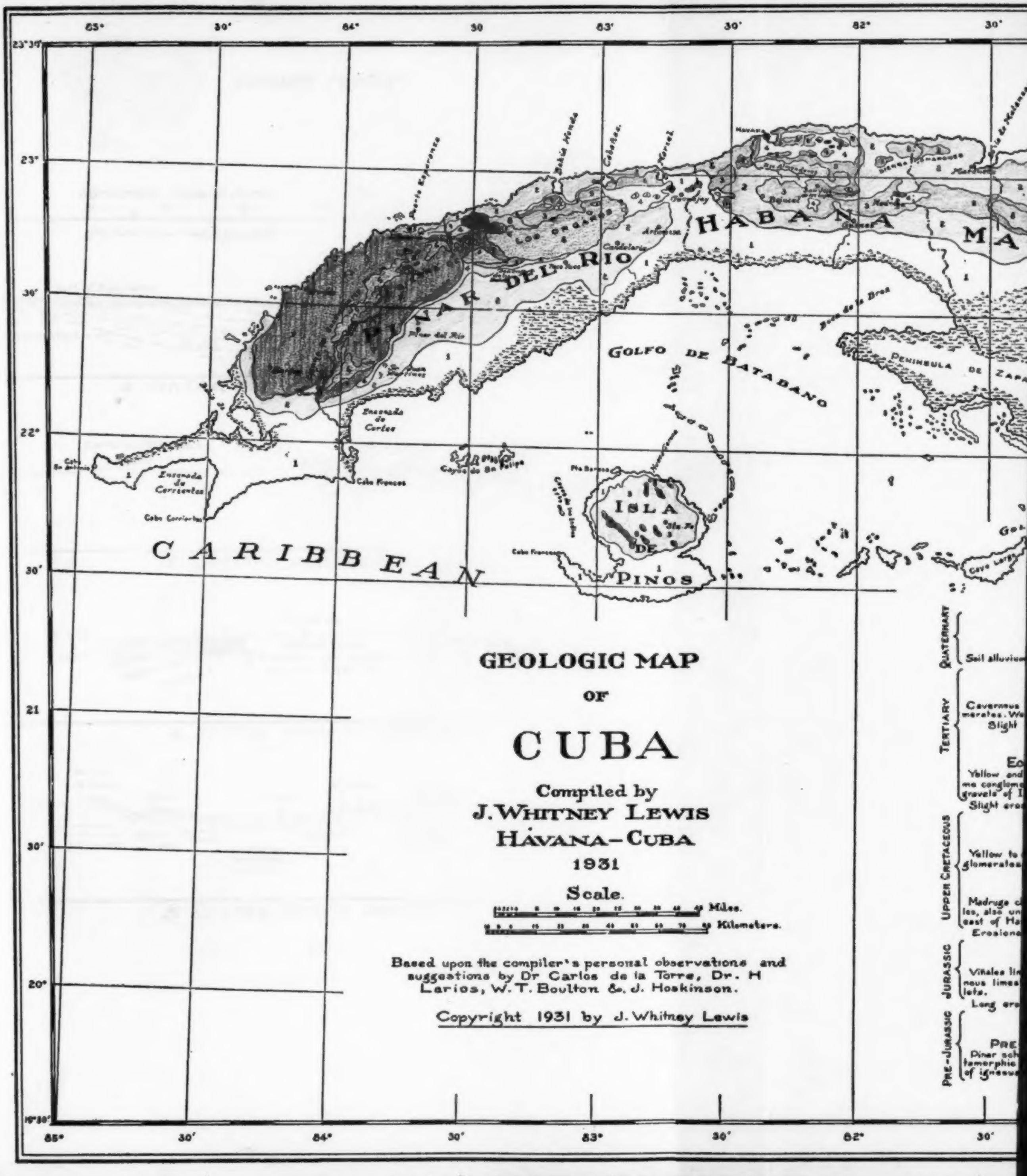
SEDIMENTS

BASEMENT

Schists, slates, granites, gniesses, and lesser portions of serpentine and metamorphosed limestone are the oldest rocks which have been observed on the island and constitute the basement upon which the post-Middle Jurassic sediments were deposited.

Pinar schist.—The most frequently observed component of the basement is the "Pinar schist." This is composed of yellowish friable mica schists and reddish shale slates with occasional thin beds of blue and brown sandstone and limestone. These rocks are a metamorphosed shale series. All are intensely faulted and folded. A sparse growth of small pine trees is characteristic of exposures of this formation and such areas are locally called pine lands or "Pinares."

These schists, covered by a thin mantle of Tertiary gravel, compose most of the Isle of Pines. They also occupy most of the northwest half of Pinar del Rio Province, where they extend throughout the broad, hilly region between Guane and the northwest coast, and can be traced continuously eastward through the valleys between, and the foothills


GEOLOGIC MAP
OF
CUBA
Compiled by
J. WHITNEY LEWIS
HAVANA-CUBA
1931
Scale.
Miles.
Kilometers.
Based upon the compiler's personal observations and suggestions by Dr Carlos de la Torre, Dr. H Larios, W. T. Boulton & J. Hoskinson.
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PINAR DEL RIO
HABANA
GOLFO DE BATABANO
ISLA DE PINOS
CARIBBEAN
PENINSULA DE ZAPATA
LOS ORGANOS
Cabo San Antonio
Ensenada de Corrientes
Cabo Corrientes
Cabo Frances
Ensenada de Cortes
Cayos de San Felipe
Pinar del Rio
Bahia Honda
Cabañas
Mariel
Havana
Batabano
Guanajay
Artemisa
Candelaria
Puerto Esperanza
Boca de la Broa
Cayo Largo
Matanzas
Bejucal
QUATERNARY
Soil alluvium
TERTIARY
UPPER CRETACEOUS
JURASSIC
PRE-JURASSIC
85°
30'
84°
83°
82°
23°
22°
21
20°
19°30'
23°30'

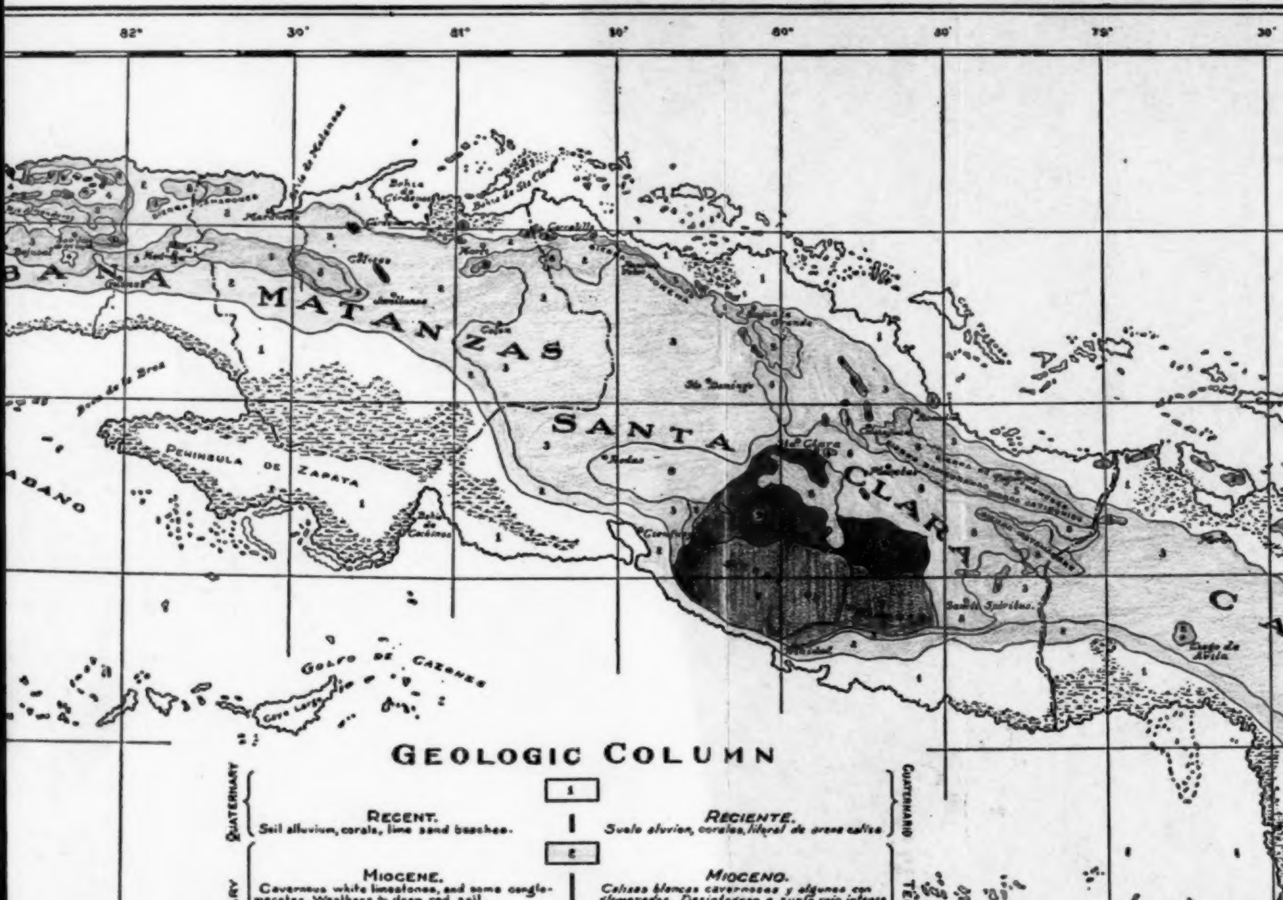
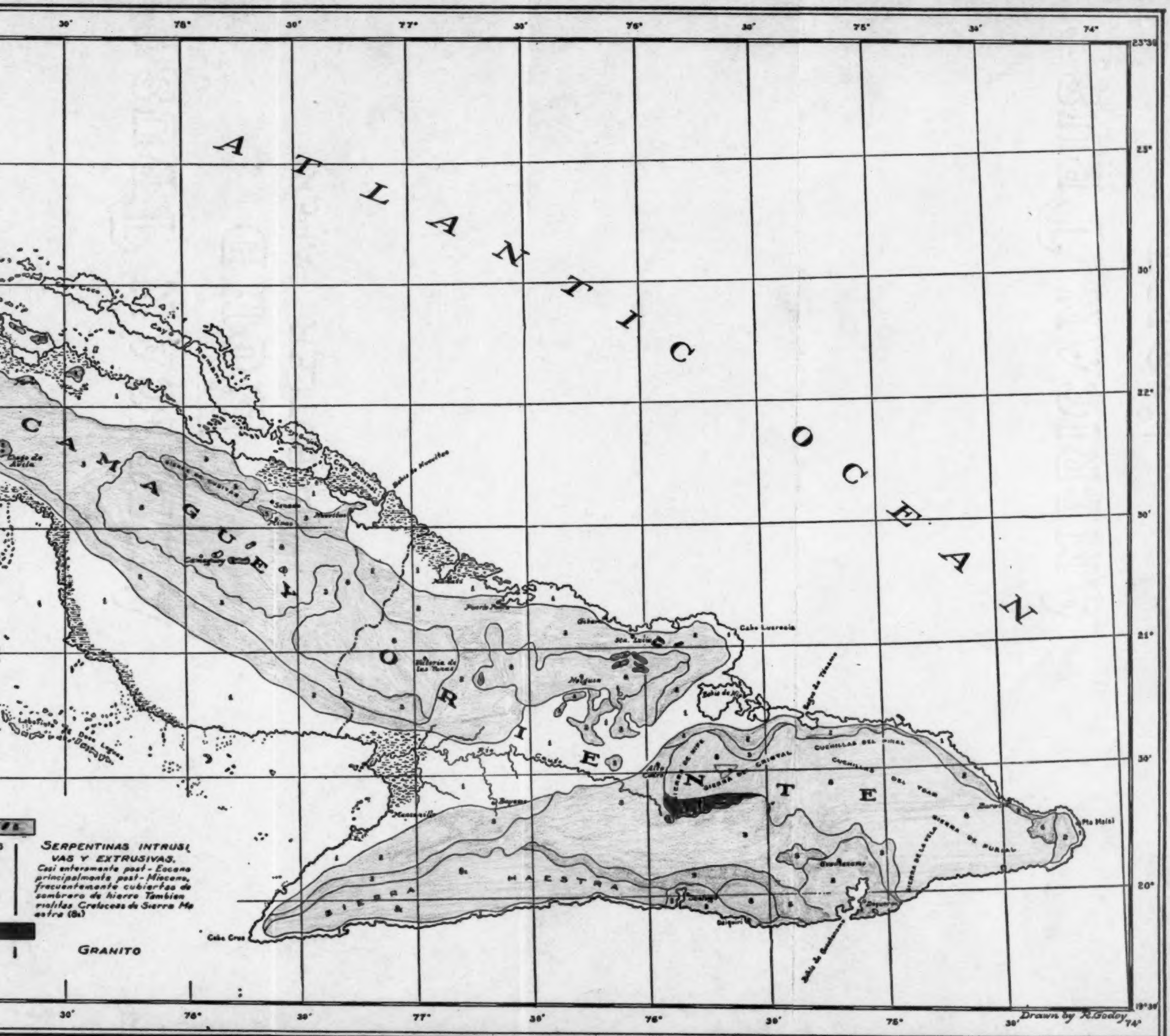

82°
30'
81°
30'
80°
30'
79°
MATANZAS
SANTA CLARA
Peninsula de Zapata
Golfo de Cazones
SEA
GEOLOGIC COLUMN
QUATERNARY
1
RECENT.
Soil alluvium, corals, lime sand beaches.
RECIENTE.
Suelo aluvion, corales, litoral de arena caliza
QUATERNARIO
TERTIARY
2
MIOCENE.
Cavernous white limestones, and some conglomerates. Weathers to deep red soil.
Slight erosional unconformity.
MIOCENO.
Calizas blancas cavernosas y algunos conglomerados. Desintegran a suelo rojo intenso
Ligera inconformidad erosional
3
EOCENE & OLIGOCENE.
Yellow and white limestones and marls. Some conglomerates. Weathers to black soil. Also gravels of Isle of Pines.
Slight erosional unconformity.
EOCENO Y OLIGOCENO.
Calizas y margas amarillas y blancas. Algunos conglomerados. Desintegran á suelo negro. Tambien gravas de Isla de Pinos
Ligera inconformidad erosional
TERCIARIO
UPPER CRETACEOUS
4
Yellow to ochre, friable, sandstones, conglomerates and clays.
Areniscas conglomerados y arcillas amarillas á ocre, friables
5
Madruga chalk and underlying Havana shales, also unclassified Cretaceous limestones east of Havana Province.
Erosional unconformity.
Yeso Madruga y Pizarras Habana subyacentes, tambien calizas Cretaceas sin clasificar al Este de la Provincia de la Habana
Inconformidad erosional
CRETACEO SUPERIOR
JURASSIC
6
Viñales limestone. Non-crystalline bituminous limestone cut by network of calcite veinlets.
Long erosional unconformity.
Caliza de Viñales, Caliza bituminosa no cristalina, intersectada por una red de venillas de calcita
Extensa inconformidad erosional
JURASICO
PRE-JURASSIC
PRE-JURASSIC UNDIVIDED.
Pinar schist, Gerona marble and other metamorphic sediments also a minor portion of igneous rocks.
PRE-JURASICO SIN DIVIDIR.
Esquisto Pinar, marmol Gerona y otros sedimentos metamorficos, tambien una parte pequeña de rocas igneas.
PRE-JURASICO
SERPENTINIC INTRUSIVES AND EXTRUSIVES
Almost entirely post-Eocene, principally post-Miocene, frequently gossan covered. Also Cretaceous rhyolites of Sierra Maestra.(8x)
GRANITE

PLATE I


ATLANTIC OCEAN
CAMAGUEY
ORIENTE
SIERRA MAESTRA
Cabo Lucrecia
Cabo Cruz
Manzanillo
Cuchillas del Toar
Sierra de Purial
SERPENTINAS INTRUSIVAS Y EXTRUSIVAS.
Casi enteramente post - Eoceno principalmente post - Mioceno, frecuentemente cubiertas de sombrero de hierro. También violitas Cretáceas de Sierra Maestra (8a)
GRANITO
Drawn by R. Godoy
78°
77°
76°
75°
74°
30'
23°
22°
21°
20°

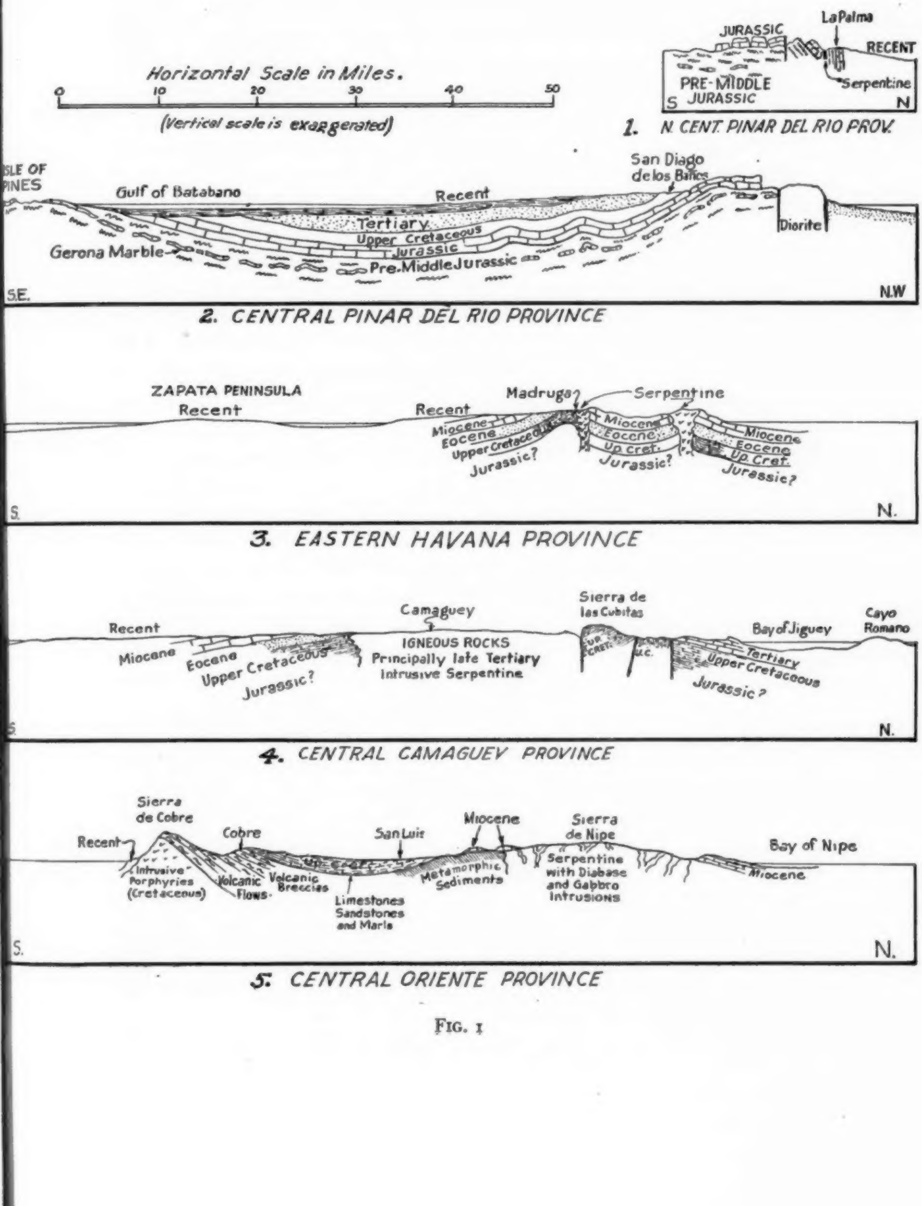

Horizontal Scale in Miles.
0
10
20
30
40
50
(Vertical scale is exaggerated)
JURASSIC
La Palma
RECENT
PRE-MIDDLE JURASSIC
Serpentine
S
N
1. N. CENT. PINAR DEL RIO PROV.
ISLE OF PINES
Gulf of Batabano
Recent
San Diego de los Baños
Tertiary
Upper Cretaceous
Jurassic
Gerona Marble
Pre-Middle Jurassic
Diorite
S.E.
N.W.
2. CENTRAL PINAR DEL RIO PROVINCE
ZAPATA PENINSULA
Recent
Recent
Madruga
Serpentine
Miocene
Eocene
Upper Cretaceous
Jurassic?
Miocene
Eocene
Up. cret.
Jurassic?
Miocene
Eocene
Up. Cret.
Jurassic?
S.
N.
3. EASTERN HAVANA PROVINCE
Recent
Camaguey
IGNEOUS ROCKS
Principally late Tertiary
Intrusive Serpentine
Sierra de las Cubitas
Bay of Jiguey
Cayo Romano
Miocene
Eocene
Upper Cretaceous
Jurassic?
Tertiary
Upper Cretaceous
Jurassic?
S.
N.
4. CENTRAL CAMAGUEY PROVINCE
Sierra de Cobre
Recent
Cobre
San Luis
Miocene
Sierra de Nipe
Bay of Nipe
Intrusive Porphyries (Cretaceous)
Volcanic Flows
Volcanic Breccias
Limestones Sandstones and Marls
Metamorphic Sediments
Serpentine with Diabase and Gabbro Intrusions
Miocene
S.
N.
5. CENTRAL ORIENTE PROVINCE

Fig. 1

on either flank of the Jurassic limestone mountains, the two ridges which lie between Pinar del Rio and Vinales, and the hills lying between the Organos Mountains and the north coast. They appear in small patches as far east as Martin Mesa in Pinar del Rio Province.

It is estimated that at least 10,000 feet of this formation is exposed in the section between Vinales and the north coast near the town of Cayetano. DeGolyer has called this exposure the "Cayetano formation" (3).[1] Similar pine-land schists are also exposed over a large area in the eastern portion of the Trinidad Mountains in Santa Clara Province.

Gerona marble (1).—Within the Pinar schists are one or more gray and blue marble members which range up to 250 feet in thickness. The most prominent occurrence of this member is near the town of Nueva Gerona in the Isle of Pines. Another extends in a narrow belt in an east-west direction through the schist area north and northwest of the town of Pinar del Rio. This may be seen on the road between Pinar del Rio and Guane and again on the road between Pinar del Rio and Vinales.

A belt of pre-Cretaceous metamorphic rocks skirting the southern flank of the Sierra Nipe in Oriente Province is mentioned by Hayes *et al.* (1), and steep-dipping pre-Jurassic schists in the Guatanomo basin in Oriente Province are reported by Darton (12).

Igneous portions of the basement probably occur in the north-central part of the Pinar del Rio Province. Granitic portions of the basement are exposed in contact with the overlapping Cretaceous and Tertiary sediments in the northern and western foothills of the Trinidad Mountains, and at several points within the serpentine mass in Camaguey Province. Some of the unclassified igneous rocks of the mountainous portions of Oriente Province may also belong to the pre-Middle Jurassic.

Many of the streams which traverse the basement carry clean quartz sands and gravels which indicate that porous clastics are probably present in such portions of the overlying sediments as are situated favorably with respect to old shore lines.

Vinales limestone (3).—Exposed in the mountains of Pinar del Rio is a series of approximately 2,000 feet of massive limestone which rests unconformably upon the base-leveled schists. This limestone is blue in color and saturated with petroleum residues in most places observed. It is not crystalline, but is cut by numerous calcite-filled veinlets. Well preserved ammonites (genus *Idoceras*) occurring in this formation conclusively identify it as Jurassic (2).

[1]Numbers in parentheses refer to list of references at end of paper.

These limestones show very few interruptions of sedimentation; however, organic shales which apparently belong near the top of the series were observed north of Candelaira and again in a small outcrop at a serpentine contact near Martin Mesa. These limestones are very soluble and contain numerous caverns and solution cavities. It is, therefore, probable that the eroded surface of this formation, where buried by younger sediments, is extremely porous. This limestone is believed to underlie the younger rocks in most parts of the island and to be the source of most of the oil and asphalt that occur in the seeps and such pools as may be present.

Barnum Brown and Marjorie O'Connell (9) have described the Jurassic column exposed in Pinar del Rio in considerable detail, identifying a sufficient number of fossils to subdivide it into its European and Mexican, Middle and Upper Jurassic equivalents.

They state that this series was deposited in a sea which encroached from the west. According to them, a thickness of 2,000 feet was deposited in the region north and west of Vinales from which the formations overlap and feather out toward the east until approximately 300 feet of the youngest portion of the series is all that remains in the east portion of the province. They believe that it is not present farther east than Pinar del Rio Province.

Artemisa limestone.—Blue-black shales and limestones containing ammonite aptychi appear in the mountains northwest of Artemisa. The total thickness of these rocks is unknown, but at least 300 feet is exposed. These rocks may be of either Cretaceous or Jurassic age. The writer is inclined to the latter view. He is also inclined to believe that the Jurassic limestone continues much farther eastward than the previously mentioned writers estimate.

Most of the contacts between the Jurassic limestone series and the underlying schists are soil covered. However, excellent exposures of this contact may be studied in the section from La Palma southward into the Organos Mountains and on the road between this point and Vinales, where considerable Jurassic limestone float occurs above the Cayetano formation.

Two deep wells were drilled south of the Organos Mountains, one at Taco Taco, and the other near Candelaria. The former was drilled to 3,161 and the latter to 4,015 feet (20). The logs of both these wells indicate that they were drilled through Tertiary and Cretaceous limestones and marls, next encountering more than 1,000 feet of Jurassic limestone, and finally entering typical Pinar schists.

It is important to note that a limestone soil extends, from most of the Jurassic limestone areas, for a considerable distance over the schists and also that schist outliers or patches of soil, which would support the growth of pine trees, are nowhere known to occur above the Jurassic limestone.

Large blocks of blue, petroliferous limestone, which lithologically resembles the Jurassic, are included within serpentine intrusions in the eastern portion of Havana Province and at a number of similar points in Matanzas Province.

In the Menendez well of the Cuban Oil Company, in the northeastern portion of the Matanzas Province, 350 feet of granite arkose containing some bits of serpentine was first encountered, then a limestone from 350 feet to 2,385 feet. This limestone resembled lithologically the Jurassic of Pinar del Rio and was impregnated with asphaltic residues from 1,115 feet downward.

At least 600 feet of dark blue petroliferous limestones cut by veinlets, which are probably Jurassic, occurs on the western flank of the Trinidad Mountains above the basal arkose and igneous masses. Also blue limestones, which may be of Jurassic age, are reported near Trinidad (1). Occurrences of gray limestones containing Jurassic ammonites are reported north of Holguin at a point 3 kilometers east of Central Santa Lucia in Oriente Province (19). Hills of what is probably Jurassic limestone occur within the serpentine area east of Holguin. Also Jurassic limestones are reported to be present in the steep mountains at the extreme east end of the island (19). The writer does not know of any occurrences of Lower Cretaceous sediments in Cuba.

UPPER CRETACEOUS

Basal conglomerate.—The oldest phase is probably the equivalent of the Texas Woodbine. The basal portion of the Upper Cretaceous consists of a conglomerate and sandstone series which rests unconformably on the eroded older rocks and probably overlies most of the Jurassic of the central and western portions of the island. In many places it contains a large percentage of igneous material and much of it is arkose. South of Santa Clara, above the granite and underlying the Cretaceous, and also west of the Trinidad Mountains overlying the Jurassic limestone, several hundred feet of this arkose was observed. The 350 feet of granite arkose found in the Menendez well mentioned previously, is another occurrence. This was probably derived from granite of the ancestral Trinidad mountain land mass. In Pinar del Rio Province it contains

considerable felspathic sand. In this province its exposures are of the same age as that of the El Cano formation.

Havana shales (3).—In Havana and Pinar del Rio provinces the lowest member of the Cretaceous that is exposed is a series of thin-bedded dark green to light gray shales and sandy shales which are composed largely of volcanic ash. This material is not sufficiently plastic to be used satisfactorily for rotary fluid. It crops out in the regional uplift along the north coast of eastern Pinar del Rio, again in the city of Havana, and eastward in the province. It is encountered in most of the deeper wells drilled in Havana Province, in several of which, at least, 2,000 feet was penetrated. It is not known to be present east of Havana Province.

Madruga chalk—Luyano of DeGolyer (3).—Overlying the Havana shale near Madruga and also in the city of Havana and eastward is a series of white chalks and marls with occasional white shales and grits. Near Madruga 800 feet was observed and a thickness of 2,000 feet was encountered in the Sage well, 20 miles west. It also appears above the Havana shales in Havana and also at Mariel, Cabanas, and Bahia Honda in Pinar del Rio Province.

El Cano formation—Lucero of DeGolyer (3).—Above this is a series of thin-bedded clay shales, sandy shales, micaceous sandstones, sandstones, and conglomerates, with occasional thin limestone members. They are yellow to ochre in color and friable.

This formation is composed principally of material that apparently was derived from the Pinar schists. However, there is a large percentage of serpentinic material in some of the occurrences in Havana Province. One of these, encountered in a well, consists of reconsolidated water-lain clastic serpentine which would be considered a serpentine sill were it not for the presence of numerous well preserved foraminifers (21).

At Madruga this series is 200 feet thick. It increases in thickness westward to Pinar del Rio, where 1,000 feet is observed in the northeastern portion of the province. This formation is exposed in a narrow belt rimming the eastern portion of the mountains of Pinar del Rio and extending throughout a large portion of the northeastern part of that province. It reappears at intervals along the crest of the anticline which extends along the northern coast of Havana Province, again near Baldspot dome, and also rimming the chalk at Madruga. No occurrences have been observed east of Havana Province.

CRETACEOUS EAST OF HAVANA PROVINCE

The Cretaceous rocks of Havana Province can not be traced continuously eastward. However, limestones containing Cretaceous fossils crop out intermittently along the major lines of deformation in Matanzas Province and eastward. Such occurrences were observed near the serpentine contact southwest of Cardenas and again near serpentine intrusions in the central part of Matanzas Province. The north coastal hills which extend from the eastern part of Matanzas through Santa Clara and just over the line into Camaguey Province, as well as the mountainous northeastern portion of Santa Clara Province, are composed of Cretaceous limestones. A total thickness of more than 6,000 feet of this section has been measured. These rocks contain so many faults that continuous sections are extremely rare. The lowest portion of this appears to be a 2,000-foot or perhaps much thicker series of white, hard oölitic limestone of undetermined age. Above this a limestone conglomerate of less than 200 feet in thickness is in some places, though not everywhere, encountered. Above this is a 3,000-foot series of blue and gray organic limestone. These rocks are cut by a network of calcite veinlets. A great portion is petroliferous. Ammonite aptychi are present in many places. This series appears to be the equivalent of the Artemisa limestone. Overlying this is an 800-foot series of limestone breccia. This is composed of angular fragments of white limestone and serpentine pebbles in a matrix of hard, white, pure limestone. Portions of this appear to be sufficiently porous to serve as reservoir beds. Above this is 1,000 feet of gray to blue crystalline limestone which contains Cretaceous foraminifers.

Cretaceous limestones overlie a considerable area of granite arkose south of the city of Santa Clara and also cap some of the foothills of the Trinidad Mountains.

The limestones which compose the Cubitas Mountains, which extend parallel to the coast in the northern part of Camaguey Province, seem to belong to this series. Fragments of these limestones ranging up to a kilometer in length are included within the serpentine areas of Camaguey and western Oriente provinces. Cretaceous pyroclastics and limestones are reported on the northern flank of the Sierra Maestra in Oriente Province. Also the lignite series which occurs in the upper Cauto Valley is probably of this age (1).

EARLY TERTIARY

Bejucal formation.—Conformably overlying the Cretaceous in Havana Province is a series of very uniformly bedded limestones and

marls, with some shales in the lower portion. The beds average 3 feet in thickness. The color of this series varies from pale green to white. It weathers to a black soil. It is exposed over a large area in the central part of Havana Province, where approximately 3,000 feet is exposed. There are also exposures of this formation in the northwestern part of Matanzas Province. It is extremely difficult to find fossils in this formation. However, a few Eocene foraminifers have been found in the middle portion.

Most of the plains northwest of the Trinidad Mountains and a narrow belt along the north flank of the eastern portion of the coastal range in Santa Clara Province are covered by white and yellowish marls, limestones, and calcareous sands, many of which are very fossiliferous. Numerous megascopic foraminifers indicate that the age is Eocene. Where this formation overlaps the serpentine west and northeast of Santa Clara, thin-bedded white chalks and marls predominate. Above these, thick beds of fossiliferous yellow limestone appear. In the northwestern portion of Santa Clara Province a maximum thickness of 5,000 feet has been measured. Yellowish Eocene marls and limestones occupy a broad belt along the southern contact of the central serpentine mass of Camaguey Province and also south and southeast of the serpentine mass in northern Oriente Province. They occur along the north foothills of the Sierra Maestra, in the plateau country south of Sierra Nipe, and also around the bays of Santiago de Cuba, Guantanamo, Baracoa and some of the other re-entrants of the coast.

Overlying the Eocene in several localities are limestones which are very similar to the members just described, but which contain foraminifers that are diagnostic of the Oligocene. These can be differentiated only by most painstaking micropaleontology.

MIOCENE

Yumeri limestone (3).—An extremely porous and cavernous thick-bedded limestone series rests unconformably upon the older formations. A maximum thickness of 1,700 feet has been observed. This limestone is very hard and brittle. It is white and gray in color. However, it weathers into a highly ferruginous deep red soil which covers many of the broad valleys and plains. Many of the denuded exposures weather into very sharp points and ridges which are locally known as "*dientes de perro*." West of the Trinidad Mountains this limestone contains thick conglomerates which are composed of water-worn igneous and limestone pebbles, and elsewhere, many limestone boulders and conglomerates

occur near the base of the series. Portions of this series contain numerous Miocene foraminifers.

This formation is well exposed in the Yumeri Valley near Matanzas. It skirts most of the coast, in places forming a line of low but sharply rising coastal hills. It also caps many of the highlands of older formations at interior points.

Gypsum occurs in the upper part of this formation at several points in the Yumeri Valley. There are also several outlier hills along the northwest coast of Camaguey Province which are composed of gypsum. These may represent a condition of landlocked lagoons.

PLEISTOCENE

Lying unconformably upon the older formations, at many points near the coast, are comparatively thin deposits of coral limestone containing Pleistocene fossils. Many of these deposits occur on the ocean terraces, which may be observed on the hills surrounding Matanzas Bay. Some of these terraces are at least 300 feet above sea-level. Similar Pleistocene terraces of lesser elevations have been noted at many other points along the coast.

QUATERNARY AND RECENT

Generally speaking, there are no broad alluvial valleys, most of the soil being derived from rocks in place. The principal exception is the broad central valley of Oriente Province, which is composed of sand, silt, and gravel from the surrounding mountains. Most of the areas of yellow and black soil in the central part of the island contain enough boulders of Eocene rocks to clearly identify the underlying formations, and the red soil with fragments of Miocene limestone is equally characteristic. The entire coast of the island, including the broad belts of swamp land, the islands and the shallows between them, and the mainland, is composed of recent corals and marls. Mangrove swamps and peat bogs are extensively developed in these areas. Almost all of the beach sands consist of lime fragments and foraminifers. The only silicious sands that were observed occur near the mouths of streams which cross igneous areas or the basement complex. The most noteworthy of these are the micaceous quartz sand beaches of the Isle of Pines.

Recent, though inactive, volcanic cones and large areas covered with volcanic bombs and ash may be observed near Holguin and Sancti Espiritus.

The great areas of surface replacements were developed in this period. These include the iron gossans of Diaqueri and Sierra Nipe in

Oriente Province, the iron and manganese replacements of the plains of Camaguey, Santa Clara, and Matanzas provinces, and the gossan of the northwest foothills of Pinar del Rio Province. Also most of the metalliferous veins occurring in all of the provinces are due to secondary enrichments that took place since the close of the Tertiary.

IGNEOUS ROCKS

Granites and serpentine belonging to the basement complex occur in a belt of frontal hills near the north coast east of Esperanza in Pinar del Rio Province, again south of Santa Clara in the Trinidad mountain region, and possibly within the great igneous mountainous region of eastern Oriente Province.

Granites which may belong to the basement appear at the town of Camaguey and elsewhere within the serpentine mass of Camaguey Province.

Rhyolites overlain by rhyolite flows and pyroclastics which grade upward into limestones of Cretaceous age form the Sierra Maestra in Oriente Province.

Stocks and elongated exposures of serpentine and chlorite appear at intervals along faults throughout the northern portion of Pinar del Rio, Havana, and Matanzas provinces. Very large masses of serpentine occur in the hills southwest of Coliseo, Matanzas Province. Other large areas of serpentine occur northwest and northeast of the Trinidad mountain system, and a great belt of serpentine extends through the center of the southeastern two-thirds of Camaguey Province and eastward into Oriente Province. Another mass extending east and west covers the region near Holguin. The commercially important chromite deposits of Matanzas and Camaguey provinces occur as magmatic segregations in these serpentine masses. This would indicate that these masses are denuded laccoliths.

These intrusions have been cut by secondary intrusions of igneous rocks of every description ranging from pegmatite to obsidian in texture. Many of these serpentine masses include large fragments of Jurassic and Cretaceous rocks. Limestone blocks several hundred meters in length have been observed on edge within the serpentine mass of Holguin and very large blocks of Cretaceous rocks have been noted in the serpentine mass of Camaguey. The smaller intrusions in many places cause very steep tilting of the late Cretaceous and early Tertiary beds at the contact.

At Cumbre and at a number of other points well within the serpentine mass large deposits of asphalt occupy vertical fissures.

The writer is therefore inclined to believe that an important portion of the serpentine-covered areas is underlain by Jurassic and Cretaceous sediments. It appears probable that most of the serpentine reached its present position by traveling vertically through comparatively narrow dikes, then spreading either as laccoliths and sills at some zone above the Cretaceous formation, or as flows at the surface.

METAMORPHISM

There appears to be no metamorphism of the post-Paleozoic sediments which is due to the depth at which they were buried or the degree to which they were deformed.

There has been regional replacement by chert and hematite over great areas of pre-Jurassic rocks in the northwestern Pinar del Rio Province and over most of the serpentine areas in Havana, Matanzas, Santa Clara, Camaguey, and Oriente provinces. In many places it is extremely difficult to determine the exact nature of the original rocks. This is especially true of the plains of Camaguey, where chert and hematite sinters cover great areas.

The hydrous silicates forming many of the intrusive masses, notably in the northern portion of Havana Province, are varied in color and of characteristic structure due to their hydrothermal genesis. However, these can not be classed as altered sediments.

There is some contact metamorphism of the limestone blocks included within serpentine masses and the sediments immediately adjoining the larger intrusions, but this condition scarcely anywhere extends more than a few feet beyond the contacts.

It seems probable that the fluids, which were contained in such porous beds as were penetrated by the dikes and stocks, were heated sufficiently at the contacts to generate vapors of sufficient pressure to force the fluids away from the contacts until the intrusions cooled. During the cooling and the formation of the secondary fissures, these vapors condensed and the fluids re-occupied the original openings and such cracks and fissures within the intrusive rocks as were connected with the original porous sediments. In places where fissures extended from petroleum accumulations to the surface, oil migrated upward, filling the crevices and fissures and escaping until the openings were sealed by residues. Such petroleum as was lost was dissipated into the air by evaporation or burning.

There is no indication that any of the original petroleum content of the sediments was lost by some underground destructive process.

The occurrence of naphtha at Motembo is especially interesting in that pure colorless naphtha is encountered in wells near the center of the serpentine mass, while light-gravity brown crude oil is found in those on the edge.

STRUCTURE

No attempt will be made to describe the detailed structure of specific areas. However, the principal trends of deformation and their characteristics will be presented.

Superimposed upon the geanticline of the island are a number of long trends of structural weakness that roughly parallel its geographic axis. Along these are a number of long and in many places broad anticlines, many of which occupy topographic highs. Their flanks are generally of uniform dip and apparently composed of unfaulted sedimentary segments. The crests are generally faulted and where incompetent beds crop out along them the dips are generally steep. The strikes of the faults are parallel with the axes of the folds and there is generally little or no throw. In areas of compression where the less competent beds are exposed there are a number of local faults of small horizontal persistence which probably are entirely superficial.

In general, it is believed that the surface rocks reflect the structure of the underlying formations. Indications of the development of important deformation within the post-Jurassic sediments before the end of the Oligocene are conspicuously absent, for in the areas of steep dip the Eocene rocks are generally tilted almost as steeply and in the same direction as the Cretaceous. There are even many exposures of the Miocene which dip at very steep angles, which indicates that an important portion of the deformation of the entire post-Jurassic column took place at the close of the Tertiary.

In this connection, a conformable sequence of Cretaceous, Eocene, and Miocene sediments may be observed along the central highway west of the town of Madruga in Havana Province, and another on the east side of Mariel Bay.

Many of the contacts are soil-covered and there are numerous instances where steeply dipping older beds are faulted into contact with more gently dipping younger beds. However, in all of the instances observed by the writer, the younger beds did not contain material derived from the older beds or the clastics which one would expect in an overlap.

Serpentine intrusions occur in many places along the folds, but are by no means general. There are several folds from 5 to 20 miles in length, along which no igneous rocks are exposed.

The most noteworthy structural trend is the chain of écheloned faulted anticlines which extends close to and parallel with the north coast for almost its entire length. Through the center of the island is another which appears in the mountains of Pinar del Rio, also in the center of Havana and Matanzas provinces, and continues eastward through the central serpentine areas of Santa Clara, Camaguey, and Oriente provinces. The structure of the eastern half of Santa Clara Province is complicated by regional dips away from the Trinidad mountain uplift. South of this trend the Cauto Valley of Oriente Province forms a broad westward-dipping syncline, south of which is the northward-dipping monocline of the Sierra Maestra which ends in the profound fault of the south coast.

GEOLOGIC HISTORY

The pre-Jurassic basement, where exposed in Cuba, the Isle of Pines, Haiti, and Puerto Rico, is composed of metamorphic sediments with smaller amounts of igneous rock, all of which are highly folded and faulted. It appears to be the base-leveled remnant of a land mass that once stood high above sea-level, for many exposures of granites and pegmatites are found which could form only at great depths.

During the Jurassic the portion of the basement lying east and south of Cuba probably remained close to sea-level, while that of the region now including Cuba and the Isle of Pines subsided with comparative uniformity and a slight northwestward inclination. Except for basal conglomerates, few if any clastics interrupted the lime deposition, and it is presumed that there were few, if any, elevated land bodies near by. Apparently the seas were sheltered and generally very shallow and vegetation was plentiful, for almost the entire series contains organic material. The total subsidence appears to have been at least 2,000 feet in the western portion.

This was followed by a gradual and uniform emergence of a great area which included Cuba and the shallow waters near by. The Trinidad mountain region seems to have been elevated at least 2,000 feet more than other areas, for south of Santa Clara the Jurassic limestone is absent. The land was completely base-leveled and a gradual submergence commenced at the end of the early Cretaceous. This was characterized by a tilting of the ocean floor away from the Trinidad Mountains both on the west and on the north and northeast. The marked

thickening toward the west, in Havana Province, of the Upper Cretaceous members is evidence on this point and is also indicative of the fact that lines of weakness and consequent tendencies toward deformation during this period were parallel with the old shore line and not with the present axis of the island. The first actual submergence, in this period, of the area which is now Cuba was the development of a broad embayment in Havana and northeastern Pinar del Rio provinces, and the deposition of the Havana shales. It appears that the remainder of the island and a great area south and east were at that time above water.

It seems probable that at the beginning of this period, volcanoes appeared immediately south of the Sierra Maestra region and extruded the rhyolite that composes most of the range. The only other evidence of vulcanism at the beginning of this period is the volcanic ash of the Havana shales, which evidently was derived from near-by submarine or terrestrial vulcanism. Subsidence continued without important interruption until the entire ancestral land mass was submerged, with the accompanying deposition of the Madruga chalk and the limestones of the areas east of Havana Province.

There is little, if any, direct evidence of vulcanism during the deposition of the Madruga chalk. However, at the end of this period several areas must have been elevated above sea-level and a number of volcanoes developed, for certain members of the El Cano formation are dominated locally by volcanic material which is intimately mixed with unaltered foraminifers. The El Cano formation, especially its western portion, is clearly derived from the Pinar schists, and land bodies in the area lying south of the present position of the island were probably present. The Trinidad mountain region probably also emerged, for the El Cano formation does not appear in that vicinity. The continued westward tilting of the ocean floor in Havana Province is evident from the westward thickening of the El Cano formation.

It appears that the deposition of the Cretaceous rocks kept close pace with the subsidence and that the seas were always relatively shallow.

A slight emergence followed this deposition. That this elevation and subsequent erosion were unimportant is indicated by the fact that the succeeding formations consist principally of marls and limestones rather than of clastics.

This emergence was followed by the gentle and continuous regional submergence of the Tertiary.

The great thickness of Eocene and Oligocene limestones in both Havana and Santa Clara provinces indicates a general subsidence, with

a continued tilting both northward and westward from the Trinidad mountain region, which probably remained slightly above sea-level. It also appears that the western portion of the Pinar del Rio Province and the Isle of Pines were above water during the first part of the Tertiary and that these areas subsided with a northeastward tilting.

Through the Cretaceous and the early Tertiary there seem to have been no noteworthy interruptions of the subsidence other than occasional oscillations of the shallow seas, for very few, if any, important angular unconformities are observed. All of the evidence now available indicates that up to this time there were no shore lines with consequent zones of weakness and lines of folding parallel with the present axis of the island.

The first important deformations of the post-Paleozoic sediments and the first important intrusions of serpentine appear to have occurred at the close of the Oligocene.

At this time an entirely new set of tectonic stresses began to develop, the building of the present mountain systems commenced, and for the first time Cuba and the Isle of Pines began to emerge from the seas in their present forms.

The nature of the platform on which the Cretaceous rocks were deposited was the dominant factor influencing the type of structure and vulcanism that developed in western Cuba. This platform consisted of a thickness in excess of 10,000 feet of incompetent mica schists, slates, and occasional limestones and sandstones, which were highly contorted and shattered before the Jurassic deposition. Over these was a continuous bed of hard Jurassic limestone, averaging 2,000 feet in thickness, and of almost continuous depositional sequence containing very few shale partings or other planes of weakness for the internal adjustment of stresses.

The manner in which this platform reacted to the late Tertiary and post-Tertiary stresses can be studied in considerable detail in the mountains of Pinar del Rio, where the Jurassic limestone has adjusted stresses by breaking into very large blocks, almost all of which are considerably greater in both length and breadth than its thickness. In most cases these are more than a kilometer wide and several kilometers long in an east-west direction. As this is the point of maximum elevation of the Jurassic, it is logical to infer that structural conditions there observed are similar to, though much more intense than, those of the portions which underlie the island toward the east.

The compressional stresses acting in a north-south direction were relieved by long east-west-trending faults in the competent Jurassic platform. These probably extended to great depths, many of them to the molten rocks, and also caused the type of deformation observable in the comparatively incompetent overlying formations.

It seems probable that the conglomeratic basal members of the Cretaceous were subjected to no contortion whatever during these deformations, and that the overlying Cretaceous and Tertiary rocks were but little disturbed other than being tilted with the fault blocks of the Jurassic, and sharply upturned locally at contacts with intrusions. Near the crests of such anticlines as developed above these faults, considerable purely superficial local faulting and steep inclination naturally took place.

It seems probable that the network of veinlets, which characterizes much of the Jurassic limestone, was formed at this time, and that these openings were sufficiently continuous to permit the migration of petroleum from the limestone to such overlying reservoir beds as were present. This probably took place before the veinlets were filled with calcite by the lime-saturated water which followed the oil in its upward movement.

It would appear that most of the serpentine which reached the surface consisted of comparatively narrow dikes and stocks along the fissures in the Jurassic limestone which became irregularly greater in width as they approached the surface, occasionally intruded as sills in the less competent members of the Cretaceous and Tertiary, and some of which spread as broad flows at the surface. In some of the larger intrusions the cooling of the serpentine seems to have caused a shrinkage of the masses which resulted in a tilting toward the contacts of the sediments immediately adjacent, even though the regional dips are away from the intrusions. In both Santa Clara and Camaguey provinces the Cretaceous rocks adjoining the serpentine masses on the north have steep dips toward the contacts, though the dips near the coast are generally northward. This is thought to be due to the subsidence of the areas immediately adjoining the intrusions into the deep-seated reservoirs of molten rock from which the serpentine was extruded. In other words, a phenomenon appeared similar to that which forms the rim synclines of salt domes.

The post-Oligocene emergence and erosion was sufficient to remove a great thickness of Eocene sediments from the regions of uplift along the north coast and also much of the Cretaceous from the mountainous parts of the island. Portions of the ancestral Organos Mountains

and the ancestral Trinidad Mountains may have been denuded to the Jurassic limestone and other portions to the Pinar schist.

During the Miocene the entire island, with the exception of the Organos Mountains, the Trinidad Mountains, the Sierra Nipe, the Sierra Maestra, and a few isolated peaks along the axis of the island, was submerged and reef limestone, marls, and limestone conglomerate, reaching, in some places, a thickness of 1,700 feet, were deposited, overlapping the slightly folded and eroded older formations. The gypsum deposits of the north coast were formed in land-locked lagoons during this period.

At the end of this period further deformation, of the same character as that which followed the Oligocene, took place. Many of the fissure systems and incipient folds developed into more steeply folded anticlines with faulted crests, and additional intrusions of serpentine and other igneous rocks occurred. From the relatively slight discrepancy of dip between the Miocene and older rocks in many of the folds, it appears that in many instances most of the deformation and intrusion of the post-Paleozoic sediments occurred at the end of the Miocene. The fact that many oil seepages occur in Miocene rocks is further evidence that a large part of the deformation took place at the close of the Tertiary. At this time the island emerged to approximately its present position.

Several oscillations of the island and important movements along the old lines of weakness have continued from the Miocene to the present. Horizontal Pleistocene terraces, some of which are several hundred feet above sea-level, indicate that the island was submerged and elevated several times without material tilting. These oscillations are probably related to the withdrawal of water from the ocean during the periods of continental glaciation. The mountains of Oriente Province and the great Bartlett Deep south of the island appear to have developed simultaneously in the latter part of the Pleistocene or possibly even Recent time. These mountains appear to be among the youngest and best defined fault-block mountains in the world. In fact, many of the fault scarps in this region are of such recent origin that no appreciable talus has formed (16). Recent severe earthquakes in this region are further evidence of movement along these faults. These faults seem to be due to the vertical movements of large blocks of the earth's crust and not to compressional forces.

Recent corals occurring far inland indicate that just before the last emergence of the island, a branch of the sea extended through the Cauto

Valley to the Bay of Nipe, separating the area on the southeast from the rest of the island. The recent, though extinct, volcanoes in the central and eastern part of the island and the live-oil seepages which occur in every province also indicate comparatively recent movements.

Post-Tertiary erosion has removed much of the Tertiary sediment, especially from areas of uplift, in many places exposing the Cretaceous rocks on the structural highs.

SURFACE OCCURRENCES OF PETROLEUM AND DEVELOPMENT

Numerous petroleum occurrences, including clear naphtha, oils resembling Mid-Continent crude, heavy asphaltic oils, and hard gilsonite are found in every province of the island. In most instances these are clearly related to fissures which extend to petroleum accumulations in sedimentary rocks. Generally the petroleum appears to have migrated upward from reservoirs close to the Jurassic limestone or possibly from source and reservoir beds in the younger sediments. The fissures developed in serpentine intrusions, due to shrinkage after cooling, have in some places acted as avenues of migration between oil accumulations in the sediments penetrated and the surface, and also as reservoirs of minor importance. Such serpentine or other igneous rocks as appear near seepages are generally incidental to the fissure systems and in no way related to the seepages. Most of the seepages appear to be of Quaternary origin, for asphalt deposits observed in mines are laminated horizontally, with little, if any, indication of vertical flow structure, which indicates that they have not been subjected to appreciable lateral compression since they were formed.

An excellent description of the better known surface occurrences of oil and asphalt on the island is already available (3). Space does not permit either its repetition or a detailed description of the exploitation of and prospecting for petroleum which has taken place. There are at least thirty asphalt mines that have been operated in the past. Two are being exploited at the present time. In one of these, the Mariel mine in Pinar del Rio Province, more than 1,000,000 metric tons of gilsonite has been proved by mining and core drilling.

Light oil is being obtained from many shallow wells in a serpentine mass at Bacuranao, 15 miles east of Havana, and colorless naphtha is being produced from a similar area at Motembo, in the northeastern part of Matanzas Province. The daily production from each area is less than 50 barrels. Approximately 20 wildcat wells have been drilled in the western half of the island, principally in Havana Province, but prac-

tically none of these was located favorably, from a geologic standpoint, nor drilled to a depth that would adequately test the formations. In most cases where geologists were employed, the wells were shifted to locations other than those recommended, because of the ownership of concessions, and in practically no instances were they drilled to the recommended horizons.

These surface occurrences of oil and asphalt are evidence that, at the close of the Tertiary, there existed widespread sedimentary and structural conditions which caused the formation and accumulation of large petroleum deposits, some of which were partially or totally dissipated through fissures.

The logical inference is that some of the unfissured anticlines still contain important deposits.

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The writer wishes to thank those geologists and mining engineers whose willingness to exchange information and comment has been of real value in the preparation of this paper. He is especially grateful to R. H. Palmer and Mrs. Palmer, H. Larios, W. T. Boulton, J. Hoskinson, R. N. Kolm, and D. McArthur. He would name several others had he their permission.

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DISCUSSION

R. J. METCALF, Fort Worth, Texas (written discussion, March 23, 1932): We believe that Mr. Lewis is in error in describing the schistose shale series in Pinar del Rio Province as a part of the pre-Middle Jurassic basement rocks. This series which has been called the Cayetano formation by Mr. De Golyer[1] is believed by us to be above the Vinales limestone. The Cayetano beds and the Vinales limestone are exposed in a major structural fold through Pinar del Rio Province and are intensely broken by a system of block faults, causing a complication of conditions which perhaps make the question of their position debatable. However, the areal distribution of the two formations in the western part of the province, where the Vinales limestone occurs near the axis of the fold with the Cayetano beds both north and south of it and having a similar angle of dip, makes it appear quite definite that the Vinales limestone underlies the Cayetano. Definite contact of the two formations as seen in the mountains about 6 kilometers north and slightly east of San Diego de los Banos, where the Cayetano definitely overlies the Vinales, shows little evidence of unconformity between the two formations.

The Vinales and Cayetano formations represent a depositional unit, the massive limestones of Vinales grading into calcareous shales of the lower Cayetano and later into ferruginous shales higher in that formation. Before the deposition of the Cretaceous, this series was tilted westward at a low angle and peneplaned, allowing the Cretaceous to be deposited on Vinales limestone in eastern Pinar del Rio Province, while on the west it rests on progressively younger strata of the Cayetano formation.

We have no definite proof of the existence of Vinales limestone through Havana, Matanzas, Santa Clara, and Camaguey provinces, although a number of folds and uplifts occur which should bring it to the surface if it exists in this area. Isolated exposures which Mr. Lewis mentions as being probably Jurassic are believed to be for the most part Cretaceous limestones metamorphosed by igneous intrusives.

[1]Geology Cuban Petroleum Deposits, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 2 (1918), p. 133.

The position of the Vinales limestone below a series of shales which have undergone such metamorphism as to become schistose in structure makes it appear extremely doubtful whether that limestone can be considered the source bed for petroleum or the asphalt deposits of Cuba. Most of the asphalt deposits are found in Cretaceous beds or in close proximity to beds of Cretaceous age and these are the most probable source of the material.

There is evidence that important deformation along the present system of folding began in late Cretaceous or early Eocene time. The Bejucal formation of Mr. Lewis, wherever observed, is much less intensely folded and faulted than the Cretaceous beneath it and it is fully as thin-bedded and incompetent to resist stresses as the Cretaceous. Exposures of the contact between the Cretaceous and Eocene are rare, but examples of it may be seen about 1 mile west of Madruga in Havana Province and 6 miles northwest of Matanzas in northwestern Matanzas Province. At both of these localities there is evidence of angular unconformity.

J. Whitney Lewis (written reply, April 5, 1932): Just prior to Mr. Metcalf's departure from Cuba in the fall of 1931, he explained his interpretations of the geology of the island to the writer. Following this the writer made a two-weeks' horseback trip through portions of Pinar del Rio Province, visiting the area north of San Diego de los Banos and other contacts along both the southern and northern sides of the central mountain system. The writer is satisfied that his interpretations and reasons therefor, as summarized in his paper under the heading of "Vinales Limestone" and "Artemisa Limestone," are essentially correct.

Especial attention is invited to the well records furnished by Mr. A. Fath and also to the section south of La Palma (Section No. 1) where the geology is simple and beautifully exposed.

Barnum Brown and Marjorie O'Connell (9) have published excellent detailed descriptions and clear photographs of several sections which show the Jurassic limestone resting unconformably on the Cayetano formation. They furnish a photograph of the Cayetano formation where exposed near the town of that name, and state: "The pronounced folding of the underlying schists on which the Oxfordian limestones rest unconformably is well shown on the road to Esperanza north of the limestone mountains." They describe well preserved ammonites, pelecypods, gastropods, fishes, and marine reptiles that occur within the unmetamorphosed Jurassic limestones and shales.

In contrast to these the Cayetano schists are so highly metamorphosed that very few fossils have been preserved. The only definitely known occurrences are poorly preserved casts of fern fronds and spores (resembling Paleozoic types) which were found near the town of Cayetano. At this exposure the schists are on edge, striking parallel with the coast and exhibiting an apparent thickness ranging from 10,000 to 20,000 feet.

The writer does not think it possible that such a great thickness of shale series could be deposited above the Jurassic sediments, then further buried by an overburden sufficiently great to produce schistosity, and finally contorted, without similarly affecting the Jurassic sediments. Moreover, it is difficult to explain how the island could have been elevated sufficiently in early Cre-

taceous time to permit the removal of this great thickness of sediments from the Jurassic now exposed. The absence of schist remnants and soil on the great fault-block mountains of but slightly tilted Jurassic limestone is also significant.

The extent of the Jurassic sediments east of Pinar del Rio Province must of necessity be a matter of speculation until the results of detailed paleontological studies are made public. The writer has already cited one reported occurrence of Jurassic ammonites in Oriente Province.

Regarding what Mr. Metcalf considers as evidence of important deformations along the present system of folding in the late Cretaceous or early Eocene, the writer can only state that numerous personal observations point to the opposite conclusion. The writer has found *Rudista* and other Cretaceous fossils in the area between Madruga and a point 2 miles west, and places the Cretaceous-Eocene conformable contact 1 mile farther west than the point described by Mr. Metcalf. The writer has not studied the area 6 miles northwest of Matanzas. DeGolyer (3) states that this is where the Yumeri limestone (Miocene) attains its greatest development. There would be considerable uncertainty attached to the identification of Eocene formations in this area unless diagnostic fossils were encountered. In fact, stratigraphic relationships in Cuba can be conclusively determined only from unfaulted contacts where diagnostic fossils are present.

The writer assumes no claim to finality. The generalizations which he draws are based upon such information as is now in his possession. He fully recognizes that this is far from complete and welcomes both additional information and other interpretations.

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FAULTS IN COMODORO RIVADAVIA OIL FIELD, ARGENTINA[1]

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ABSTRACT

This article is a summary of the material published on the structural conditions of the Comodoro Rivadavia oil field by the Bureau of Mines and the Oil Administration of the Department of Agriculture of the Argentine Republic. The formations are much faulted, with resulting complications in structure. Other difficulties are irregular bedding, pinching sand bodies, and variable cementation. It is difficult in this area to map underground structure from surface indications.

INTRODUCTION

In this discussion, mention is made of two branches of the Department of Agriculture of the Argentine Republic, namely, the Dirección General de Minas, Geología, e Hidrología, and the Dirección General de Yacimientos Petrolíferos Fiscales. For convenience, these will be indicated, respectively, as the Bureau of Mines, and the Federal Oil Administration. Credit is due the geologists of the Bureau of Mines for the groundwork of the knowledge of the stratigraphy of the oil district proper, and the surrounding region, while the studies of the geologists of the Oil Administration have led, in the past four or five years, to an entirely new conception of the tectonics of the oil field.

Some interesting results of the geological work of the Oil Administration have been published in several articles in Spanish, issued mainly in the *Boletin de Informaciones Petrolíferos* of the Oil Administration, Buenos Aires, which apparently have had little circulation among geologists in the northern hemisphere. This paper is a summary of the material published on the structural conditions of the Comodoro Rivadavia oil field.

DISCOVERY AND DEVELOPMENT OF COMODORO RIVADAVIA OIL FIELD

Often Comodoro Rivadavia is cited as an example of accidental discovery of an oil field. Indeed, it was not one accident, but a lucky series of accidents, which led to the discovery.

[1]Read by title before the Association at the Oklahoma City meeting, March 26, 1932. Manuscript received, March 5, 1932. Published by permission of the director general de Yacimientos Petrolíferos Fiscales, Argentina.

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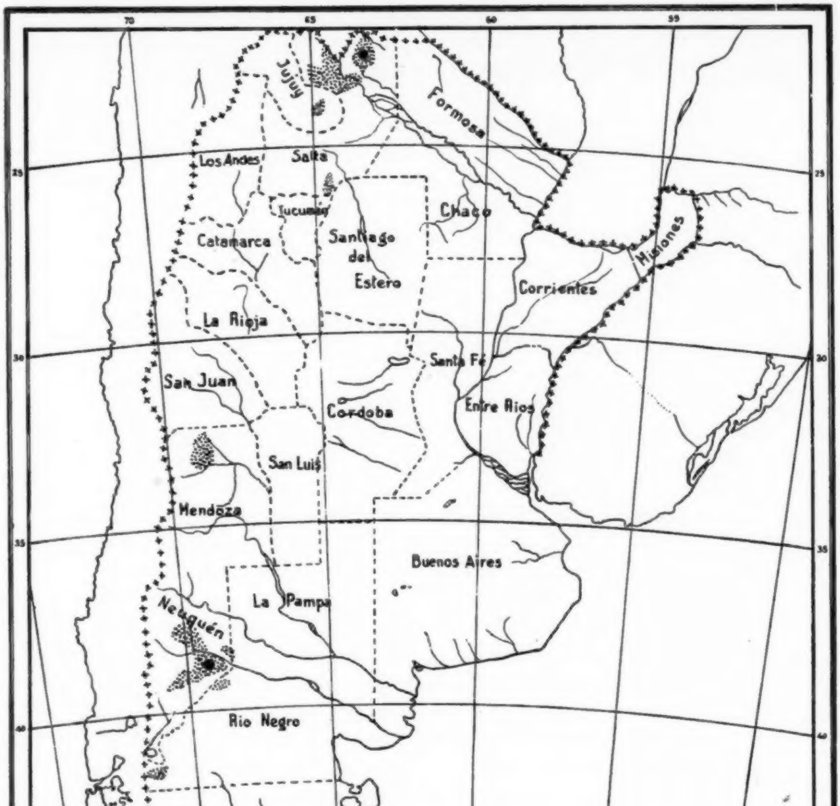

FIG. 1.—Index map of Argentine Republic, showing Government-operated oil fields at end of 1931 (black circles) and areas which have been and are being studied by geologists of Federal Oil Administration (stippled areas).

In the first years of this century, the village of Comodoro Rivadavia began to acquire importance as a wool trade center; but its progress was hindered by the lack of drinkable water in its environs. Then the Government sent a party from the Bureau of Mines to drill a well intended to supply drinking water to the village. When this well had reached a depth of 165 meters without finding water, it was abandoned because of technical difficulties. We now know that in that location it would be highly improbable to strike an oil accumulation of any importance. In March, 1907, a new well (afterward the Y. P. F. No. 2) was begun approximately 3 kilometers north of the first well. It reached the theoretical limit of the drilling equipment (Fauck, for depths of 500 meters) without finding drinkable water, but as the hole was in good condition, the drillers, after exchanging a few telegrams with their superiors in Buenos Aires, tried to drill deeper in hope of finding the desired water. At the depth of 535 meters they found the first showings of oil, December 13, 1907. There was no explosion, or blowing-out of tools, such as those reported by Loomis;[1] on the contrary, the well was always under control.

As soon as the news was known, the Executive Power issued a decree (December 14, 1907) forbidding the granting of permissions for exploration, and also the taking of claims, in a circular area whose center was that of the village, and whose radius was fixed at 25 kilometers; actually, it was a semi-circular sector, because its center is very near the coast.

During the following three years (1908-1910), five other wells were drilled by the Bureau of Mines. Three were very near the discovery well, one about 1,500 meters southeast, and one more than 3,000 meters north-northeast. The last (No. 5) found a strong flow of gas at a shallow depth (about 150 meters), ran wild, and burned. Although commercially unproductive, it must be considered as the discovery well of the best pool known in the vicinity of Comodoro Rivadavia.

On September 6, 1910, a law restricted to 5,000 hectares the area reserved to the Government, and the unrestricted area was soon covered by requests for concessions, mainly only for speculative purposes. On December 24, 1910, an executive decree appointed a special committee, known as the Dirección General de la Explotación del Petroleo de Comodoro Rivadavia, to administer the Government oil field of Comodoro Rivadavia. Some years later this committee extended its action to other oil fields and took the name of Dirección General de Yacimientos Petrolíferos Fiscales.

[1] B. H. Loomis, *Hunting Extinct Animals in the Patagonian Pampas* (New York, 1913), p. 94.

At first there was a certain skepticism, in Argentina, about the possible development of the Comodoro Rivadavia oil field, especially because of the common opinion that such heavy oil could be utilized only as a cheap fuel. But it seems that soon there was a reaction in public opinion, for on May 9, 1913, a new executive order recommended to the Department of Agriculture "a careful exploration" of the area bounded by the parallel of Pico Salamanca, the meridian which extends 30 kilometers west of the center of the village of Comodoro Rivadavia, the parallel 46°S., and the limit of the territorial waters on the Atlantic side. The same decree prohibited the taking of claims in that area, respecting, however, the rights previously acquired. This area is called the "Zona reservada por decreto 9 de mayo de 1913" (Fig. 2).

Between the end of 1910 and the middle of 1913, the Government had drilled only three or four new wells, all very near the existing wells. The year 1912 marked the entry of private companies: the Astra and the Compañia Argentina de Comodoro Rivadavia (the concession of the second being now operated by the Compañia Ferrocarrilera de Petroleo).

Between the middle of 1913 and the beginning of 1924, the Government oil field was fairly well developed, but only in the interior of the "Antigua Zona de reserva de 5,000 hectáreas"; and there were, by the end of 1923, more than 250 drilled holes. In the same period, several geologists of the Bureau of Mines studied the vicinity of Comodoro Rivadavia and a considerable part of the inland. One must recall the names of Hans Keidel, Richard Stappenbeck, Richard Wichmann, and Anselm Windhausen as the geologists who laid down the foundation of our actual knowledge of the stratigraphy of that region. To A. Windhausen we owe also the publication of a very complete summary of the observations and opinions of these men.[1]

An executive decree, dated January 10, 1924, committed to the Bureau of Mines the exploration in search of oil accumulations, and extended the area reserved to the Government in southern Patagonia to the parallel 45°, to the meridian 70° W. Greenwich, and to the parallel 47°. In the same year another decree, of October 30, authorized the Oil Administration to drill exploration wells in the interior of that reserve zone, provided they be not farther than 10 kilometers from any producing well; all this was independent of the exploration being done by the Bureau

[1] A. Windhausen, "Lineas generales de la constitución geológica de la región situada al oeste del golfo de San Jorge," *Boletin Academia Nacional de Cordoba* (Argentina, 1924), tomo 27, entrega 3a.

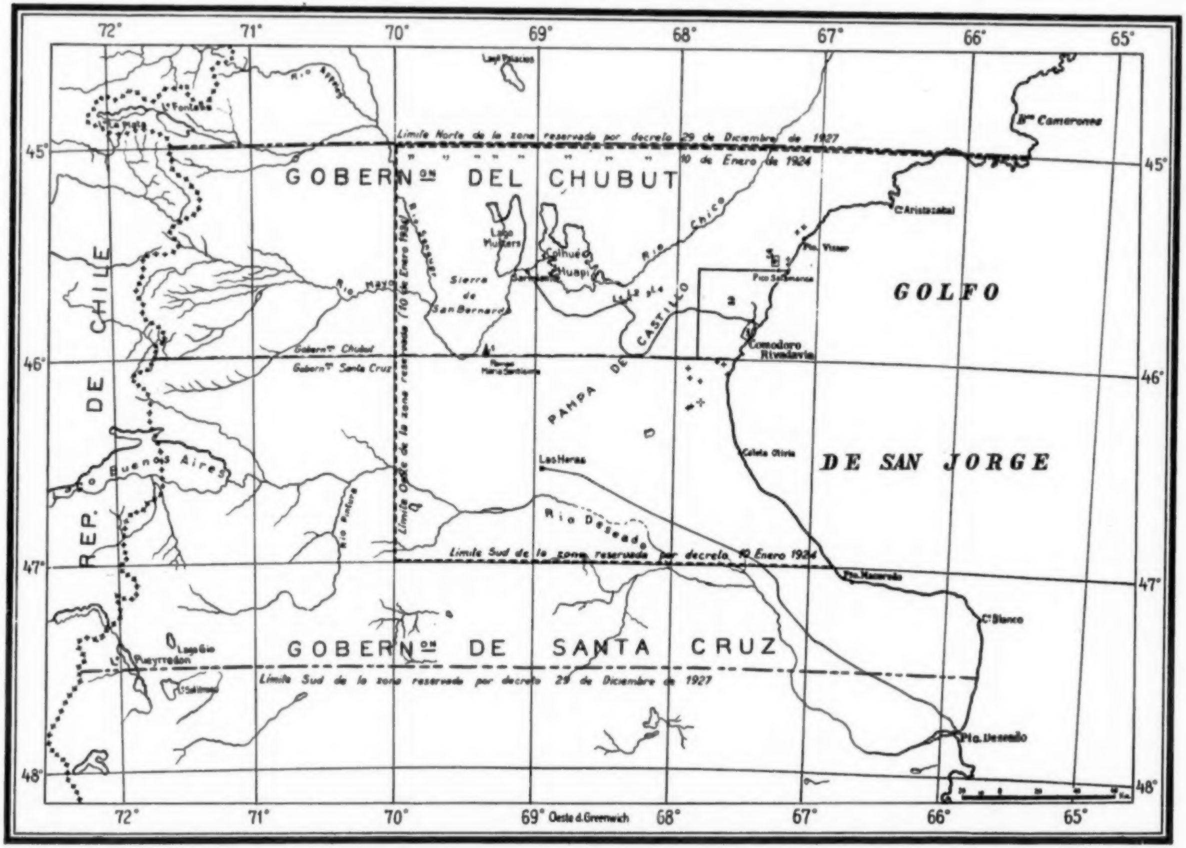

FIG. 2.—Map of part of southern Patagonia, showing Original Reserve zone (1), zone reserved by decree of May 9, 1913 (2), and extensions of reserved zone, by decrees of January 10, 1924, and December 29, 1927. Gas discoveries at Pampa Maria Santisima (A-1) and near Pica Salamanca are shown thus: (*). The recent oil discovery at Cañadon Perdido (L-4) is shown thus: (,). A cross indicates a dry hole. Width of map, approximately 560 kilometers (350 miles).

of Mines, which officially remained and still remains the institution to which belongs the investigation of the mineral wealth of the country. Finally, an executive decree of December 29, 1927, increased once more the zone reserved to the Government until its western limit reaches the Chilean frontier and its southern limit is the parallel 47° 30′.

The writer has no knowledge of exploration work accomplished by the Bureau of Mines after 1923 in the region around Comodoro Rivadavia; he knows only that great efforts have been made by the Oil Administration and by several private companies in the hope of finding new oil fields. Only in a few cases have these efforts been rewarded by important discoveries of rich pools.

In the years 1924, 1925, and 1926, the Oil Administration employed three geologists (Guido Bonarelli, Egidio Feruglio, Vladimir J. Vinda), principally for local studies on small areas of particular interest. At the beginning of 1927 the necessity of a methodical study of the reserved zone was felt, and the writer was charged with the organization and direction of a geological party (named "Comisión Geológica para el estudio de la región del Golfo de San Jorge") for the economic survey of the region. This party, which is still at work, has mapped on various scales the most interesting parts of the reserved zone, has suggested almost a hundred locations for test wells, and has investigated carefully the structural conditions. Since June, 1929, the chief of the party has been Egidio Feruglio. Subsequently, Clemens Leidhold has taken particular charge of the subsurface geology of the Oil Administration's producing area in the vicinity of Comodoro Rivadavia.

At the end of 1931, the total number of Oil Administration wells exceeded 1,300 in the region of Comodoro Rivadavia (including those which were drilling). Of these, almost 100, that is, nearly 7.7 per cent, are exploratory wells.

Recently, an important gas showing was found in the Oil Administration's most distant exploratory well, A-1, located about 140 kilometers (87 miles) west of Comodoro Rivadavia at a locality known as Pampa Maria Santisima. This well also had several small showings of heavy oil. Drilling was continued, and by the end of 1931, the well had reached a depth of 1,500 meters (4,950 feet). In the original reserve zone, well No. 860 is being deepened to test horizons deeper than the present producing zone.

The Astra, the Ferrocarrilera, and the Compañia Industrial y Comercial have each drilled a few hundred wells; the Diadema Argentina, with its subsidiaries, has only a few score of wells, but a more promising

area for future development. The concessions of other companies seem to be of less importance.

REGIONAL GEOLOGY

It would be very difficult, if not impossible, to define the boundaries of the oil district of Comodoro Rivadavia, because it has been too little explored by wells; but we can, somewhat arbitrarily, consider it the same as the "Zona reservada por decreto 10 de enero de 1927" (Fig. 2), because in this area we know many outcrops of oil sands and a number of favorable structures, mostly yet unexplored by the drill.

Geologists agree in believing that this part of Patagonia was essentially a continental region, at least from the late Triassic on. In Jurassic time and in earlier Cretaceous, the Pacific Ocean encroached over the western part of the area; Jurassic and Lower Cretaceous beds containing marine fossils occur between the 70° and the 72° parallels, not very far from the western limit of the "Zona reservada por decreto 10 de enero de 1927," but not even remnants of them have been found in the coastal zone, where the study of the outcrops and of the logs of the wells seems to indicate that older eruptive rocks (not marine Cretaceous or Jurassic sediments) immediately underlie the Upper Cretaceous or even more recent formations. However, we do not know whether there was no marine deposition in Jurassic and older Cretaceous time, or whether such marine sediments were eroded entirely in the explored part of the coastal zone.

Between the middle of the Cretaceous and the middle of the Tertiary, continental conditions prevailed, with the deposition of an enormous thickness of clastic and pyroclastic sediments, in part very rich in remains of terrestrial organisms. More than 2,000 meters of thickness belong to the so-called "Chubutiano," which formation consists of a series of beds evidently of continental origin, but including a few horizons with small pyritized foraminifers. M. Casanova[1] and E. Feruglio[2] think it is an indication of a temporary marine invasion from the east. However, the writer remembers that in the mouth of an English river many living dwarf foraminifers have been collected and described, that the dwarfed size of marine organisms seems due to an excessive propor-

[1]M. Casanova, "Intercalaciones de capas de origen marino en el Chubutiano del subsuelo de Comodoro Rivadavia," *Boletin de Informaciones Petrolíferas* (Buenos Aires, 1930).

[2]E. Feruglio, "Nuevas observaciones geologicas en la Patagonia Central," in *Contribuciones de la Dirección General de Yacimientos Petrolíferos Fiscales a la primera reunión nacional de geografía* (Buenos Aires, mayo-junio, 1931).

tion of iron salts, and that the South American rivers are, at present, the richest in iron salts in the world, so far as the writer knows. Therefore, the writer is inclined to believe that these pyritized dwarf foraminifers are an indication of estuarian or deltaic conditions; and that such an interpretation would be consistent with the scattered bones of dinosaurians and the incomplete, rounded trunks of big trees, which show the effects of having been carried a long time by the waters of a great river. The Chubutiano might correspond with the Turonian and with the Lower Senonian; but the correlations of the Cretaceous and early Tertiary faunas and floras of Patagonia with those of the northern hemisphere are always somewhat questionable.

Before the end of the Cretaceous, the Atlantic encroached upon the eastern part of the present region of the Gulf of St. George, reaching approximately the 69° 30′ meridian. That is the "Salamanquean" ingression; the Salamanquean sediments attain a thickness of more than 200 meters near the present coast, and thin out gently toward the west. The fossils collected in the Salamanquean formation seem to point to a Maestrichtian age.

The Salamanquean marine cycle began with the deposition of glauconitic sands, followed (in the eastern part only) by a few meters of gray shale, containing great numbers of small oysters, locally named "la Fosilifera," then a thick series of greenish shales, also with some marine fossils, and finally another glauconitic sand, very similar to the lower one, but only a few meters thick. Since 1923 the bottom of the "Fosilifera" has been selected as a key horizon for structural mapping in the field. As this gray shale bed thins out gradually toward the west and disappears, it is more convenient to use as a key horizon the top of the lower glauconitic sand, which underlies the "Fosilifera" where this exists.

After this Salamanquean marine ingression, continental conditions predominated again everywhere until the so-called Patagonian ingression, which, according to many geologists, seems to have begun in early Oligocene, although it is probable that it reached its western limit somewhat later (Miocene ?). Then the sea retreated at some time in the Miocene, and at that time this part of Patagonia emerged definitely.

Summarizing this short sketch of the geological history of our region, we can say that there is a very thick series of continental deposits partially interrupted by three wedge-shaped intercalations of marine sediments; the oldest wedge, whose edge faces the east, is formed by Jurassic and Lower Cretaceous beds; the other two, pinching toward the

west, consist of certain Upper Cretaceous and middle Tertiary deposits. Such a predominance of continental conditions during the deposition of the whole series makes the task of the oil geologist very difficult, because of three of its consequences, namely, (1) the scanty and poor fossil content, (2) the irregularity in composition, porosity, and thickness of most beds, (3) the close resemblance of sediments of various ages, because those sediments have been formed, directly or indirectly, from the same older rocks, without the changes and additions which marine organisms are able to perform.

In the Comodoro Rivadavia field, oil and gas accumulations of commercial importance are known in the upper part of the "Chubutiano" and in the lower part of the "Salamanqueano," that is, in a typical continental or estuarine formation, in the sediments deposited during the transition from continental to marine conditions, and in the first shore sands laid down by the advancing Salamanquean sea.

Farther west, an important gas showing and small showings of oil have been found in numerous horizons of a part of the Chubutiano which has not been reached by wells in the eastern productive area. In the well A-1, at Pampa Maria Santisima, 1,500 meters (4,950 feet) of these beds have been penetrated.

The results of the well A-1 are inconsistent with the idea, formerly almost universally accepted, that the Comodoro Rivadavia oil and gas accumulations are derived from shallow sea or lagunal sediments deposited at the beginning of the Salamanquean ingression. To the writer it seems more probable that those hydrocarbons were formed in some shore belt, or rather in a series of coastal lagoons, along the border of a continent, or even a large island, that may have existed in the early Cretaceous, or in the Jurassic, or even a little before. Later, the faulting afforded to the hydrocarbons an easy way to ascend; and along some of the faults they could reach the sands of the Chubutiano and of the Salamanquean, where we are now exploiting them.

In the Comodoro Rivadavia district there is a sharp contrast between the western strongly folded zone (anticlines of Sierra San Bernardo, Sierra del Castillo, et cetera) and the coastal zone, where folds are either absent or almost imperceptible, although a very gentle regional dip can be observed southeast of the Tertiary outcropping beds. In the vicinity of Comodoro Rivadavia, the outcropping lower Tertiary beds are crossed by several faults, many of whose throws are insignificant at the surface, but very considerable at a greater depth, especially in the oil beds, as shown by hundreds of well logs.

The sharp contrast between the coastal zone and the interior is perhaps more apparent due to the extensive upper Tertiary and partly post-Tertiary deposits of the interposed Pampa de Castillo. These younger sediments, which are neither folded nor faulted, perhaps hide a structure of an intermediate type in the lower formations.

It is evident that in such a region of long continental deposition, interrupted by partial marine encroachments, there must be several unconformities. Indeed, the unconformities abound, but in many places it is very difficult or impossible to detect them, because of the general lack of angular unconformities, the similarity in lithologic character of beds of different formation, and the irregular bedding of certain continental sediments.

EVOLUTION OF KNOWLEDGE OF STRUCTURE OF OLD GOVERNMENT RESERVE OF COMODORO RIVADAVIA ("ANTIGUA ZONA DE RESERVA DE 5,000 HECTÁREAS")

The best known part of the oil field, that is, the "Antigua Zona de Reserva de 5,000 hectáreas" (Original Reserve zone), with a little of its western continuation (Campamento Oeste of the Oil Administration) is now to be considered.

The surface geology is very simple. There is a series of Tertiary beds, apparently conformable, which belong to two well defined formations: the lower, of continental character, composed of whitish tuffs with remains of mammals and one species of land snail, is probably Eocene in age; the upper, marine and probably Oligocene in age, is the Patagonian formation already mentioned. Both are covered and hidden in many places by recent eolian sediments, carried and accumulated in the sheltered places by the dominant wind, which blows from the west. In the Original Reserve zone, the Tertiary beds are not perceptibly folded; they dip very gently south or southeast. Accurate investigations by the Oil Administration geologists, carried on in 1927 and 1928, showed that there are several faults, whose throws nowhere exceed a few meters; they have been observed only in the outcrops of the whitish tuffs of the lower section of the Patagonian formation (Fig. 3).

R. Wichmann studied the Comodoro Rivadavia oil field between 1917 and 1919, having at his disposal the logs and some of the samples of more than sixty Oil Administration wells. He believed that the beds in the oil-bearing formation were also horizontal, and finding that the distribution of oil and gas was very irregular with respect to the structure

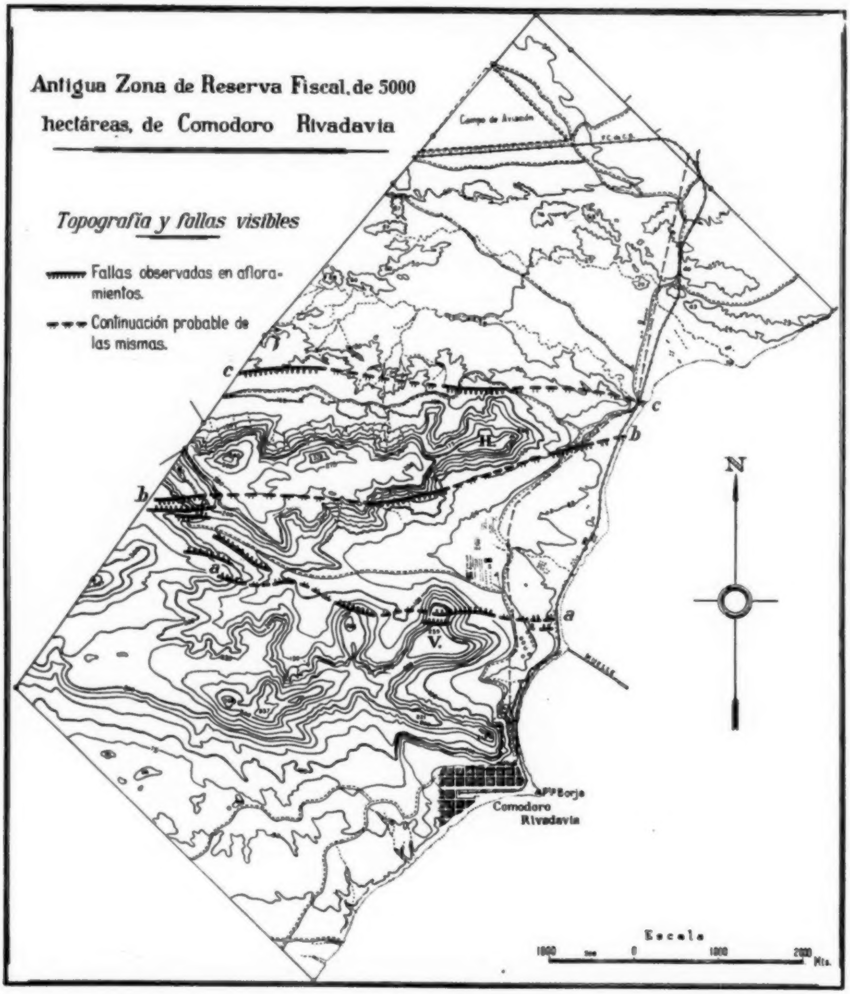

FIG. 3.—Original Reserve zone of 5,000 hectares (12,350 acres), at Comodoro Rivadavia. Topography and visible faults. Solid lines indicate faults seen in outcrops. Broken lines indicate probable continuation of same. Short lines indicate downthrown side of faults. Width of southwest end of Reserve zone is 5,000 meters (3.1 miles). *H* = Cerro Hermitte. *V* = Cerro Vitau.

postulated, concluded that the oil reservoir was composed of a series of lenticular sand bodies.[1]

At that time such a conclusion was almost inevitable, because then the "anticlinal theory" reigned without restrictions and was accepted in its literal sense. Prospecting for oil in South America was synonymous with hunting for closed structures; many geologists believed seriously that the only favorable structures in the world are domes or brachyanticlines. As it was evident from the inspection of the logs of the first fifty or sixty Oil Administration wells that there was no dome or anticline, the opinion became prevalent that there was no structure at all, and that the distribution of the oil depended only on the facies of the oil-bearing formation.

Four or five years later we find the first published attempt at a structure map of the oil field in the important memoir of A. Windhausen, already referred to.[2] This shows one main anticline trending northeast, with three secondary structures (domes) along its axial part. There is no indication of observed or inferred faults; however, noticeable features were the axes of domes II and III crossing the axis of the main anticline, and the very steep dip of the southern side of dome III. These features might lead one to suspect a more complicated structure. In this map of A. Windhausen, as in all those following, the key horizon is the bottom of the "Fosilifera."

About 1926, G. Bonarelli, then chief geologist of the Oil Administration, prepared a structural map of the Original Reserve zone, based on the logs of about four hundred wells. This map represents a surface with three steps, two of them facing each other, the southern oriented like the middle one. These steps can not be interpreted as erosion forms, but only as asymmetrical anticlines, inasmuch as the map has been constructed on the assumption of the continuity of a well defined key bed.

In the same year, 1926 (as stated in the annual report of the manager of the Comodoro Rivadavia oil field), the logs of some new wells indicated that there must be a great fault, crossing the northern half of the Original Reserve zone.

In 1927 and 1928, the members of the writer's geological party spent a part of the winter in looking for faults on the surface, and E.

[1]R. Wichmann, "Estudio geologico de la zona de reserva de la Explotación Nacional de Petroleo en Comodoro Rivadavia," *M. G. H. Boletin 25*, series B (Buenos Aires, 1921).

[2]A. Windhausen, *op. cit.*, Pl. 9.

Feruglio and A. Stessin were able to find and map several of them, the principal faults being shown in Figure 3. It appears that the fault discovered in the oil-bearing formation by the wells drilled in 1926 occurs a little north of the surface fault, but it must be taken into consideration that the throw of this fault is a few meters at the surface, and several scores of meters in the oil beds.

Subsequently a very detailed and critical analysis of the logs showed that the faults are much more numerous than previously supposed. In August, 1931, the writer endeavored to sketch a structural map of the Original Reserve zone, indicating more than twenty faults (Fig. 4).

Further and closer investigations of C. Leidhold lead to the supposition that the faults indicated in Figure 4 are only a few of the many which exist. The recent studies of Leidhold, yet unpublished, deal with a comparatively small area at the western limit of the Original Reserve zone. On the basis of a structural map and a series of well logs prepared by Leidhold, the writer has endeavored to represent, by a block diagram in isometric projection, the surface of the key horizon in one square kilometer of the area exploited by the Oil Administration (Fig. 5). This square kilometer belongs for the most part to the Original Reserve zone, although its northwest corner falls beyond these limits, but still within the properties of the Oil Administration.

Comparing Figure 4 with Figure 5, one sees that in the former there are shown only two faults (the larger one and the eastern part of another facing it), while in Figure 5 there is a veritable net of faults which divide the oil formation into prismatic or pyramidal blocks, whose horizontal section does not exceed a few hectares (1 hectare = 2.471 acres) in surface.

It has been observed repeatedly that on the downthrown side of the faults the oil production is almost as good as on the upthrown side; indeed, in a few places it is even better. Figure 6 gives an idea of the number of producing wells on either side of some of the principal faults, in the Original Reserve zone. Figure 7 shows some of these wells on a larger scale with the indication of their initial production (the small numbers in the white circles indicating cubic meters per day).

IMPORTANCE OF FAULTS IN COMODORO RIVADAVIA OIL DISTRICT

Hitherto only the Original Reserve zone and a little of the area which lies near its western boundary (Campamento Oeste) have been considered, because it is there obvious that the interpretation of structural conditions was modified by the increase in the number of the wells

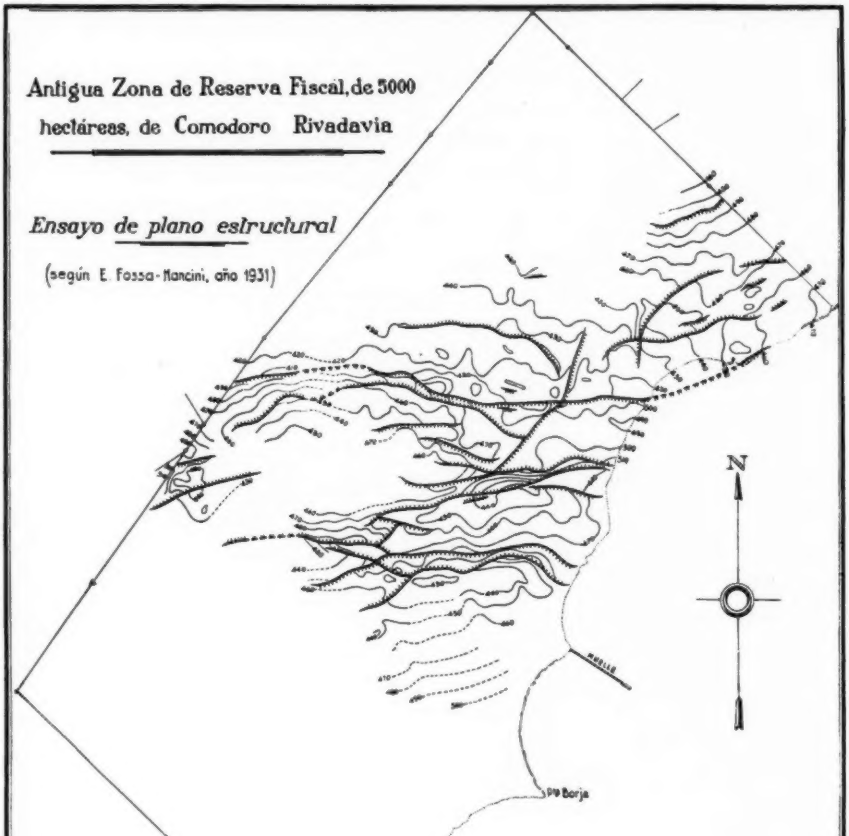

FIG. 4.—Original Reserve zone, showing subsurface structure, based on more than 1,000 wells. Contour elevations are in meters below sea-level, on the base of "Fosilifera," which occurs a short distance above oil zone. Short lines on faults indicate downthrown side. Width of southwest end of Reserve zone is 5,000 meters (3.1 miles).

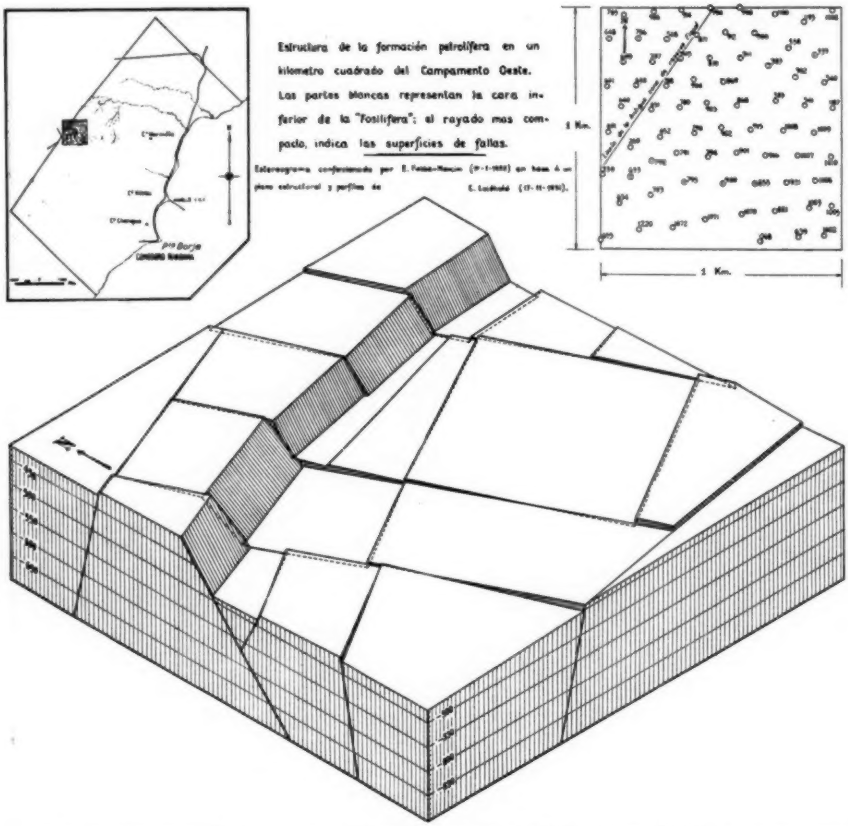

FIG. 5.—Structure of oil zone, in a square kilometer of the West Camp. White areas represent lower surface of "Fosilifera." Ruled areas represent fault planes. Stereogram prepared by E. Fossa-Mancini, based on unpublished cross sections and structural map by C. Leidhold. Elevations are shown in meters below sea-level.

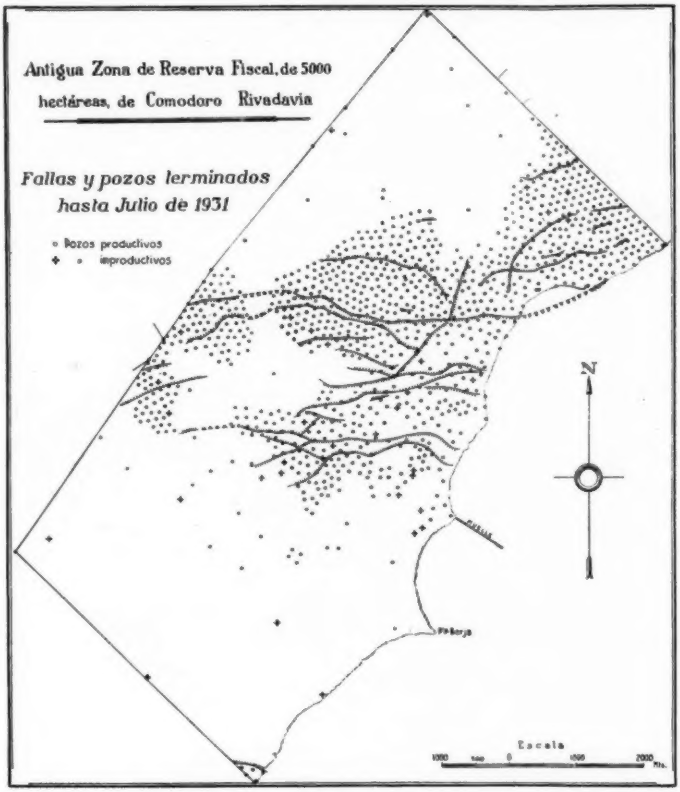

FIG. 6.—Original Reserve zone, showing faults and completed wells as of July, 1931. Circles indicate producing wells. Crosses indicate dry holes. Width of southwest end of Reserve zone is 5,000 meters (3.1 miles).

drilled and by a certain decrease in faith in the opinions previously held as unquestionable.

Examining other oil-producing areas in the vicinity of Comodoro Rivadavia, where good logs are available from enough wells, evidence is found of a large number of faults. It is known that faults are especially abundant in a recently discovered area, now exploited by the Oil Administration (Cañadon Perdido; discovery well B-1, which struck oil in 1928). Indeed, this was not a surprise, as the writer, since the end of

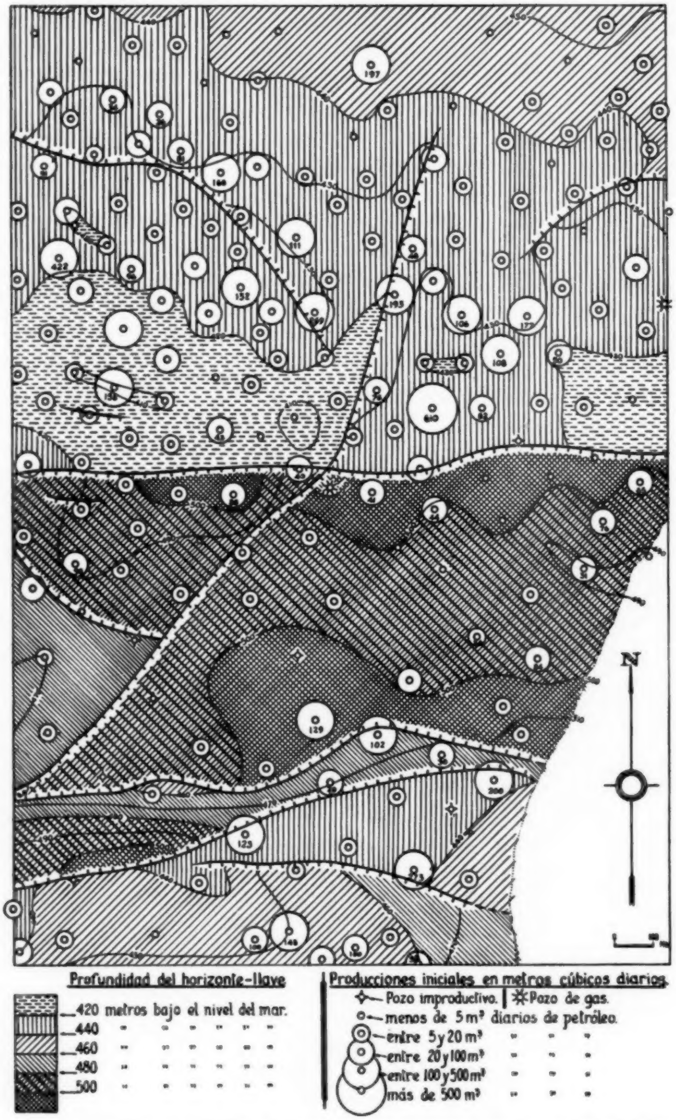

FIG. 7.—Diagram showing small area in north-central part of Original Reserve zone, crossed by the large fault of Valle *C* (*cf.* Figure 3), indicating initial production of wells (in cubic meters per day). Shading and contour elevations indicate depth below sea-level in meters. Circles around wells indicate initial production, as follows: less than 5 cu. meters (32 bbls.) per day; between 5 and 20 cu. meters (32-126 bbls.) per day; between 20 and 100 cu. meters (126-630 bbls.) per day; between 100 and 500 cu. meters (630-3,150 bbls.) per day; above 500 cu. meters (3,150 bbls.) per day. Width of map is 1,630 meters (1.2 mile).

1927, had recommended a few locations for test wells in this area, with the explicit purpose of finding a certain fault whose existence was suspected, and which was believed to be related to an important oil pool developed by the Diadema some kilometers farther west.

A series of investigations with seismographs and torsion balances, accomplished by the Oil Administration's geophysical party (directed by Mark C. Malamphy and D. Ramaccioni, respectively) showed that the terrane is cut into small blocks by many faults both near the coast of Bahia Solano and along the eastern border of Pampa de Castillo, 30 or 40 kilometers farther inland.

However, proceeding farther west, to the outcrops of the Upper Cretaceous beds, we find that there are few faults and several more or less marked folds, among which are the anticlines already referred to (Sierra San Bernardo, Sierra del Castillo, et cetera). Some of these anticlines have been described by E. Feruglio.[1] It is interesting to point out that some of the western great anticlines—for example the one cut by the bend of Senguer River—are affected by great longitudinal faults.

In this region there were periods of great volcanic activity in the late Triassic, in the Jurassic, in the Upper Cretaceous, in the older Tertiary, and also, probably, at the end of the Tertiary or at the beginning of the Quaternary. Naturally, some faults were utilized by the magma as ascending channels, and are now seen filled by dikes of basic alkaline rock. Recently the Oil Administration drilled two exploratory wells (L-1 and L-2) in the middle of a group of such dikes, with the hope that the shattering due to the intrusion of the magma had been favorable for the accumulation of oil. These wells were dry, but oil was found only a few kilometers farther east (Oil Administration).

The writer believes that some of the faults in the vicinity of Comodoro Rivadavia are very old; perhaps they affected the old basement of Triassic and (unknown) pre-Triassic rocks. It is possible that these faults partly caused the sinking of the blocks of this basement, thus preparing the way for the advance of the Salamanquean sea.

The fault planes were, naturally, loci of less resistance; thus, every new tectonic stress promoted new movements of the blocks along those fault surfaces. Therefore, the throw of these faults is always greater in older than in newer formations. We know of several instances in which the upper limit of these faults reaches the lower third of the Patagonian formation; but very seldom is it possible to find them higher. One may

[1] E. Feruglio, "Apuntes sobre la constitución geológica de la región del Golfo de San Jorge," *Boletín de Informaciones Petrolíferas* (Buenos Aires, 1929).

say that in the Comodoro Rivadavia oil field there are buried faults in the outcrops of strata of the middle Patagonian or even younger sediments, and half-buried faults in the outcrops of the lower Patagonian or the older Tertiary whitish tuffs. As an example of such a half-buried fault may be mentioned the northern fault of those shown in Figure 3; as stated previously, it has only a few meters of throw where it crops out, and more than 80 meters in the oil-bearing strata.

PRACTICAL IMPORTANCE

It is now a well known fact that in the vicinity of Comodoro Rivadavia the oil geologist can not trust very much to surface structure; here he can find, at the best, some small faults which *possibly* correspond to important faults in depth. Again, he can find a few almost imperceptible folds, which may reflect uplifted or sunken faulted blocks. If well acquainted with that peculiar "mesetas" landscape, he can also find in the topography valuable indirect indications of possible underground complications. But, on the whole, it is a very difficult task for the oil geologist to infer the underground structure from the little he sees on the surface.

And this is not all. Each of the many faulted blocks may act as an independent unit as far as the distribution of oil and gas is concerned. Indeed, in the oil-bearing formations of Comodoro Rivadavia, the shales considerably exceed the sands. Thus, in each fault there must be more or less drag; hence, the somewhat plastic shales were stretched, the sands partly disintegrated and mingled with the shaly material. Therefore, it is probable that many fault surfaces have been sealed by a more or less continuous sheet of shale or sandy shale. But other faults remained partly open, and along these moved the natural fluids, as proved by the richer accumulations of oil and gas close to certain faults, and also by the calcite veins observed in several cores. As there are no limestones among the beds traversed by the wells of Comodoro Rivadavia, the calcite is almost certainly derived from the dissolution of marine shells of the Salamanquean formation and the subsequent deposition is accomplished by circulating waters.

It seems highly probable that all the oil has come from below, ascending along some fractures which may have been formed by tension when the beds which now are oil-bearing were gently warped, but not yet broken into innumerable blocks. Indeed, there are groups of producing faulted blocks (for example, those of the northern and middle parts of the Original Reserve zone) which seem to be the fragments of

an older anticlinal arch, while other sterile groups of blocks may once have belonged to synclinal troughs.

Certainly in some places there is, or has been, a connection between adjacent blocks, perhaps due mainly to rotational faulting. In the rotational faulting there may be an area of no drag, close to the intersection of the fault surface with the rotation axis. In that area there will be no impermeable plastering of the fault walls, and, therefore, fluids can pass, eventually, from one sand in a wall to the same or to another sand, in the opposite wall, provided that the cut ends of these sands cross each other in that area.

In such a closely faulted oil field, there can be almost endless complications, due essentially to the faults. Moreover, in the Comodoro Rivadavia oil district are further sources of difficulties in the irregular bedding, the pinching-out of some of the sand bodies, and in the variable degree of cementation of others. It is no wonder that so many dry holes have been drilled in this district, especially at a time when no one suspected that the underground conditions are so different from the conditions which prevail in most oil fields of the northern hemisphere.

Now the *existence* of many structural complications is fairly well known. Geologists well acquainted with the peculiarities of the Comodoro Rivadavia oil field and with the surface geology of that region, can indicate with a certain approximation the location and the trend of some buried faults. Unfortunately, they can not foresee whether or not these faults are associated with oil accumulations of commercial importance. Therefore, the exploration work in the vicinity of Comodoro Rivadavia remains a difficult and hazardous task.

Only 100 kilometers, more or less, west of Comodoro Rivadavia (that is, where the folded Upper Cretaceous beds crop out), can the geologist rely on the surface structure; but there the distance from the coast and any trade center, the poor means of communication, and the scanty water supply, make the exploration of that zone unattractive, at least during the present period of low prices.

There are, however, enormous areas which might profitably be tested for oil and gas by powerful organizations, even if one may not depend on an *immediate* reward. For a government institution, as is the Oil Administration, the finding of reserves for the future is a no less important task than that of developing its present producing fields.

SOME ARTICLES ON GEOLOGY OF COMODORO RIVADAVIA OIL FIELD ISSUED IN *BOLETIN DE INFORMACIONES PETROLÍFERAS*

M. Casanova, "Intercalaciones de capas de origen marino en el Chubutiano del subsuelo de Comodoro Rivadavia" (1930).

———, "Sobre el significado de los granulos y cristales dolomiticos, sideriticos y ankeriticos observados en areniscas y arcillas de las formaciones petrolíferas del Comodoro Rivadavia y de Campamento Vespucio" (1930).

E. Feruglio, "Apuntes sobre la constitución geológica de la región del Golfo de San Jorge" (1929).

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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SHALLOW SALT-TYPE STRUCTURE IN PERMIAN OF NORTH-CENTRAL TEXAS[1]

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ABSTRACT

In the Permian area of north-central Texas, in south-central Wilbarger County, there is abnormal deformation which has been known to geologists for several years, but which has not been adequately described. There is approximately 250 feet of uplift accompanied by faults. The closed part of the structure occupies an area of approximately 2 square miles. An analysis of the data, both surface and subsurface, shows that all the movement occurred above a depth of 1,200 feet. The accepted causes of folding for this region do not explain the observed facts at this dome, and the conclusion is drawn that the folding, which was shallow, was due to a movement of shales impregnated with gypsum toward a point of weakness, in a manner similar to the formation of gypsum and salt domes.

INTRODUCTION

In the fall of 1924, the writer was first shown the very abnormal structural deformation in south-central Wilbarger County, Texas, which has been seen by many of the geologists who have worked in that area. Although it has been mentioned in the literature, it has not been adequately described, and now that much additional information is available as the result of drilling and core testing, these data are assembled and some conclusions are drawn about the nature and origin of the deformation.

STRATIGRAPHY

The rocks normally exposed in this vicinity belong to the lower part of the Permian, being shales overlying the Lueders formation of upper Wichita-Albany age. However, on the crest of this structural feature the alternating limestones and shales of the Lueders formation are exposed. The limestones are dark gray, light gray, and buff, and range in thickness from a few inches to 3 feet. The shales are predominantly gray and occupy more of the section than the limestones. The thickness of the Lueders is approximately 125 feet. Although the entire

[1]Read by title before the Association at the Oklahoma City meeting, March 24, 1932. Manuscript received, February 24, 1932.

[2]Consulting geologist.

section is not exposed locally, it may be studied approximately 4 miles farther southeast, where it crops out. In the part of the Lueders exposed on the dome there are five limestone beds present.

Above the Lueders occurs a typical Red-bed series of red shales, sandy shales, and red and gray sandstones, mostly unindurated. Farther south and southeast in Baylor County the lithologic character of the Lueders is similar to the outcrop on top of the structural "high," but because of a change in the conditions of deposition, on the east, north, and northeast, the gray limestones and shales grade into red beds in many respects similar to the Clear Fork.

Between the Lueders and the base of the Coleman Junction limestone, which is the oldest formation considered in this paper, a study of the logs of the dry holes shows that the limestones are more important in the lower part of the section and are as thick as 40 feet. These limestones alternate with blue and gray shales for the most part, although some brown and red shales are logged. The same conditions of deposition that affected the Lueders were continuous throughout Wichita-Albany time, and on the east, where this formation crops out, instead of the limestone and shale section, red shales and red and gray sandstones are present.

SURFACE STRUCTURE

The regional surface structure of the area is that of a gently northwest dipping homocline interrupted by local deformation of different types, all of which have very gentle dips, some of them being difficult to detect without the aid of instrumental work. It is approximately 4 miles southeast from this dome to the nearest point where the Lueders is exposed. The sea-level elevation of the Lueders is approximately the same at both these exposures. As the normal rate of dip is about 50 feet per mile, it is seen that this formation is approximately 200 feet higher on the dome than it should be. Reference to Figure 1 shows that the structure is indicated at the surface both by the areal geology and by the dips of the beds. There is a generally circular inlier of Lueders within the Red-bed series, and the diameter of this inlier at the points of maximum width is approximately 1,500 feet. Probably the most striking feature is the intensity of the folding and the attendant faulting. Dips are recorded as high as 68° and they range from this amount to a minimum dip of 37°, although most of them are nearer the larger figure. The folding is most intense on the east side and it is here that the most complicated faulting is found. In addition to the folding, the higher part of this dome is much faulted, there being many more faults than

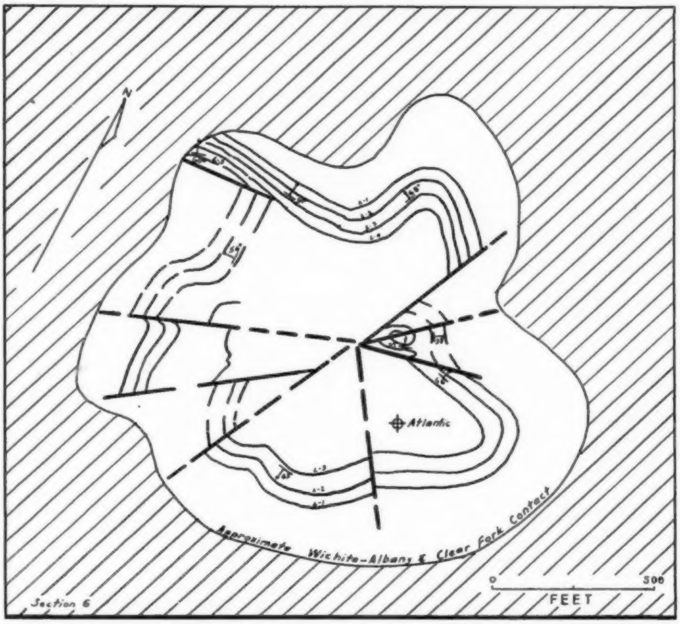

FIG. 1.—Surface structure, showing limestone outcrops and surface dips, Wilbarger dome.

shown on the surface map. It was not practicable to map all of the minor faults. The most striking characteristic of the faults is the pattern, for with one exception they radiate from a common center like the spokes of a wheel. Another feature worthy of notice is that the northwest part of the dome is upthrown and the southeast part downthrown. The one fault which does not fit in this general pattern is on the northwest edge of the surface inlier and strikes almost east and west. The amount of vertical displacement between the northwest and southeast sides of the dome is estimated at 100 feet or less, and the throws of the minor faults are estimated in terms of a few feet.

SUBSURFACE DATA

Figure 2, a core-drill map in the vicinity of the area under discussion, was furnished through the courtesy of William J. Nolte, of Fort Worth, Texas. It is part of a much larger map made for the Marland

Oil Company, comprising most of the south half of Wilbarger County. The topmost limestone of the Lueders was used as datum and in most of the core holes this horizon was checked by drilling to several of the lower limestones of the series. The results of this work correspond very closely with the foregoing interpretation of the surface structure and show the presence of a dome that has a closure of 250 feet. Comparison of the core-drill structure with that of the surface shows that only the tip of the dome has been exposed by the erosion of the Red-bed series above, the diameter of the inlier being approximately 1,500 feet, whereas the diameter of the core-drilled structure is more than 2 miles. One additional feature revealed by core drilling is the closed syncline southeast of the dome.

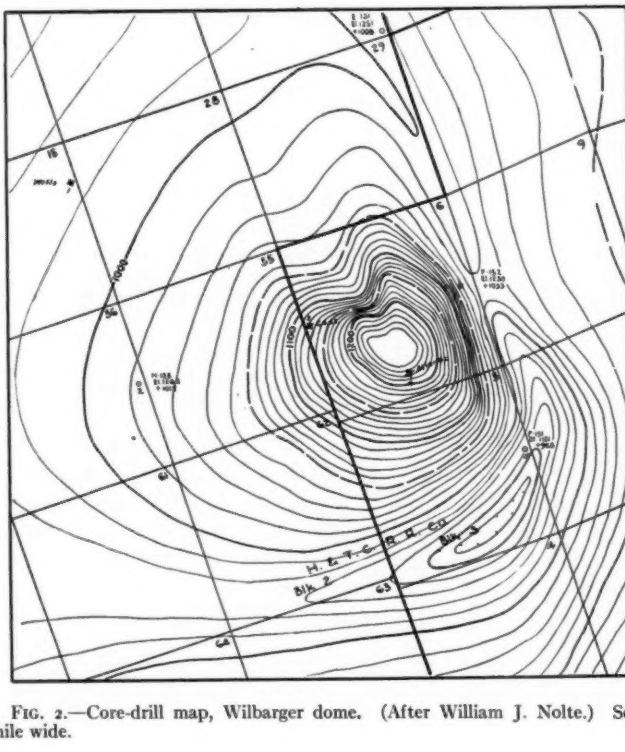

FIG. 2.—Core-drill map, Wilbarger dome. (After William J. Nolte.) Section 1 mile wide.

As a result of a study of the horizons deeper than the Lueders, a very interesting condition is found to be present. A cross section (Fig. 3) is presented in support of the foregoing conclusions and, in addition, shows the relation between the shallow and deeper folding and faulting. Three dry holes and two core holes drilled by the Marland Oil Company are included in the section which traverses the area approximately east

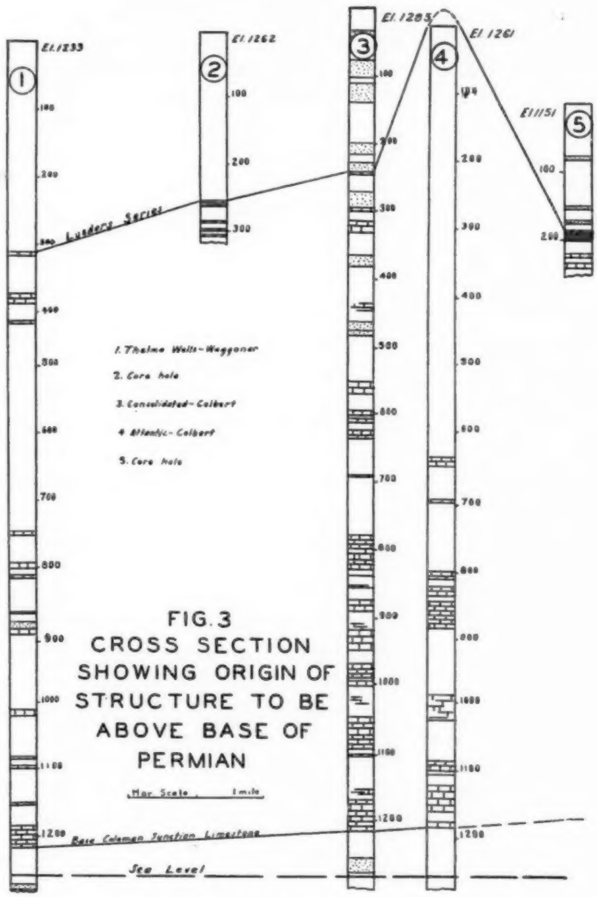

FIG. 3.—Cross section, Wilbarger dome.

and west. Below the Lueders the most reliable formation for correlation purposes is the limestone at the 1,200-foot level in the dry holes. This limestone has been correlated as the Coleman Junction by all geologists in the Wichita Falls district and marks a definite lithologic break in the section between the dominantly limestone series above and the red and blue shales, sandstones, and limestones below. The limestones above this have never been used for correlation in this area, due possibly to irregular deposition. Figure 3 does not show any of the formations below the Coleman Junction limestone. All of the formations below this limestone correlate accurately and establish its structural position as shown on the cross section. Correlation on the base of the Coleman Junction limestone shows that at a depth of only 1,200 feet the dip is almost normal, and that all of the movement indicated on the surface and in the core holes has been above that depth.

CAUSE OF MOVEMENT

There are several possible explanations of the origin of the deformation, the most important of which are listed and the merits of each discussed: (1) folding of the entire sedimentary section by compression; (2) differential settling of the sediments around a very steep and sharply pointed buried igneous peak; (3) deep igneous intrusion; (4) shallow igneous intrusion; (5) movement of the gypsiferous shales toward a point of weakness in a manner similar to that in salt and gypsum anticlines.

The first three explanations are not discussed, for they are ruled out by the fact that they presuppose an origin below the Coleman Junction limestone, and this is contrary to the facts already established. The idea of a shallow igneous intrusion satisfies the condition that the point of origin is above the Coleman Junction limestone, but there are objections which make it untenable. Some positive evidence about the presence or absence of a shallow igneous intrusion was sought by making a magnetic survey, in the belief that any intrusion as shallow as this should be reflected. As a result of this survey, the top of the dome was found to reflect less magnetic intensity than the areas lower down on the flanks, and no evidence of a large, shallow igneous intrusion was found. Furthermore, a study of the log and the cuttings from the well drilled on top of the dome shows nothing penetrated that could be interpreted as igneous rock.

It seems that the most reasonable explanation of this abnormal feature is that the movement is similar to that in salt domes, as indi-

cated by the pattern of the areal geology and by the arrangement of the faults, both being clearly the result of upthrust. That the shales could act like salt or gypsum is not unreasonable, as these Wichita-Albany shales are impregnated with gypsum and their plasticity is attested by the behavior of concrete pavement laid in the area of outcrop. Within a few months of being laid, the blocks of pavement begin to buckle and move, and this is particularly noticeable on the slopes. It is regrettable that no core hole was drilled on top of the dome so that the details of the structure of the shales could be studied, but core drilling has shown that the shales in this particular horizon are extremely contorted elsewhere in the area. The movement of shales was sufficient to elevate the Lueders in the well on top of the dome, increasing the interval between the base of the Coleman Junction limestone and the top of the Lueders more than 220 feet. Until further evidence to the contrary is produced, the conclusion here outlined seems to be the best explanation for this exceptional condition.

TIME OF MOVEMENT

From the available data, it is possible to determine the time of the formation of the structure with some degree of accuracy. As the Coleman Junction limestone was not uplifted and the heavy limestones in the lower half of the Wichita-Albany do not seem to have been disturbed, the movement clearly occurred after mid-Wichita-Albany time. It is also probable that it occurred after the close of the Lueders, since it has been uplifted more than 200 feet and very little if any disturbance could have occurred before its deposition. To limit the end of the movement is more difficult because the field evidence is not definite. The closest reliable dips in the Red-bed series are nearly ¼ mile from the steeply dipping limestones and at this point show no signs of having been disturbed by the movement, as the dips are nearly normal. At the point where the fault on the northwest flank of the dome passes under the Red-bed series, there is no evidence of its cutting these beds, although the outcrops are so poor as to leave this point in doubt. This evidence would tend to localize the movement at the end of the Wichita-Albany, but it is also possible that some of it could have continued to a later time.

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BOGGY CREEK SALT DOME, ANDERSON AND CHEROKEE COUNTIES, TEXAS[1]

H. J. McLELLAN,[2] E. A. WENDLANDT,[2] and E. A. MURCHISON[2]
Tyler, Texas

ABSTRACT

Boggy Creek salt dome is located near the axis of the East Texas geosyncline in Anderson and Cherokee counties. It is of interest principally because it is the only interior salt dome in East Texas or Louisiana on which an oil field has been developed. Surface geology first attracted attention to this area, and later exploration was carried on by core tests and geophysical work.

This dome has many of the physiographic and structural features characteristic of other interior domes, but is unusual in shape, size, and other respects. A structurally low central area is found on top of the dome. Faulting is present near the south end of the uplift.

The salt movement probably occurred contemporaneously with that of other East Texas domes, being most pronounced between middle Wilcox and Carrizo times. In the central and northern portions of the dome, salt movement also occurred after the deposition of the Lower Claiborne beds.

Oil and gas is produced from the Woodbine formation in a long, narrow area on the southeast flank of the dome. The oil-producing area contains about 200 acres and the gas area about 50 acres. Present average daily production is about 1,000 barrels. Ultimate recovery from this field is not expected to exceed 4,000,000 barrels.

INTRODUCTION

The Boggy Creek salt dome derives its name from a small stream which flows into Neches River on the west side of the uplift. The Boggy Creek dome is of interest because it is the only interior dome in East Texas or Louisiana from which oil or gas has been produced in commercial quantities. This was the first new East Texas dome to be discovered since the finding of the original six interior salt domes many years ago. The discovery of oil on this dome brought about intensive geological and geophysical work in East Texas, which led to the discovery of a number of other salt domes and structures, including the Van oil field.

The writers wish to acknowledge their indebtedness to Wallace E. Pratt and L. T. Barrow of the Humble Oil and Refining Company for permission to publish this paper, to Sidney Powers and Donald C.

[1]Read before the Association at the Oklahoma City meeting, March 24, 1932. Manuscript received, March 7, 1932.

[2]Humble Oil and Refining Company.

Barton for constructive criticism, and to M. A. Davey for some of the early history. The areal geologic and surface maps, with some modifications, represent the work of G. M. Knebel, formerly with the Humble Oil and Refining Company.

LOCATION

Boggy Creek dome belongs to the group of interior domes found in the East Texas geosyncline, being located in Anderson and Cherokee counties about 7 miles northeast of the village of Neches and 9 miles west of Jacksonville. Neches River, which separates the two counties, flows across the center of the dome.

Other salt domes in the vicinity are Brooks, 9 miles north, Brushy Creek, 6 miles west, and Keechi, 12 miles southwest. The southern portion of the East Texas oil field is 27 miles northeast.

HISTORY

The existence of shallow oil in the Jarvis area, 10 miles south of Boggy Creek, was known as early as 1887, when several shallow wells were drilled there by Henry Mayo, of Pennsylvania. Attracted by the oil showing in this area, M. A. Davey came to Palestine in 1903, and thereafter was identified with practically every oil development which took place in Anderson County. In 1904 he drilled a well near Jarvis, to a depth of 1,200 feet, and shortly after that time contracted to drill two 1,200-foot tests for the Ezell-Bell Company, in which he owned a one-fourth interest. In 1911 he induced the Ninety-Nine Oil Company, a subsidiary of the Texas Company, to take over his leases and drill three more wells. The Texas Company became interested in this county again in 1915 and drilled five wells on the Keechi dome and two wells in the Jarvis area.

Through his association with geologists, Mr. Davey became interested in applying geological methods in the finding of oil. Impressed by the unusual surface features found near Boggy Creek, he assembled a block of leases there in the spring of 1924. As a result of geological work by W. F. Bowman, Lyman Reed, and Paul Applin, the Rio Bravo Oil Company purchased leases on 1,000 acres of this block.

On November 11, 1924, drilling was started on a core test, known as Earle and Ragsdale No. 1. Samples were examined by Mrs. Paul Applin and according to her determination the top of the Midway was reached at a depth of 650 feet, which was considerably above normal. On the strength of this information, Mr. Davey interested the Humble Oil and

Refining Company, through Wallace E. Pratt, in purchasing leases on 2,000 acres of his block.

After geological work by G. M. Knebel and determinations on core-test samples by Miss Alva C. Ellisor, the Humble Oil and Refining Company purchased the balance of the block and also acquired additional leases. An agreement was made with the Rio Bravo Company whereby the development of the entire block was to be carried on by the Humble Company for the joint account of the two companies. During the years 1925 and 1926 an intensive program of exploration was conducted, including geological work, core-test drilling, and geophysical work. The geophysical work indicated the presence of salt and its approximate outline.

The first deep test to be drilled was the Earle and Ragsdale No. 1. This well encountered salt at a depth of 2,562 feet and was abandoned in salt on July 25, 1926. The second well, Templeton No. 1, was abandoned in Georgetown lime at a depth of 3,447 feet, no Woodbine being encountered. The third well, Elliott and Clark No. 1, cored Woodbine sand showing oil at a depth of 3,838 feet and was completed on March 19, 1927, with an initial production of 62 barrels of oil per hour through a ¼-inch choke. For about a month this well was closed in. After being placed on production, it soon showed salt water. An attempt to shut off the water by plugging back was unsuccessful. This well produced only about 15,000 barrels of oil before it went entirely to salt water.

Elliott and Clark No. 2, located 150 feet west of Elliott and Clark No. 1, was completed as a gas well on November 10, 1927, and showed that the Woodbine sand dips very sharply away from the dome at that point.

The thirteenth well drilled in this area, and the second to produce oil, was Lizzie Smith No. 1. This well was located in Anderson County, 1¾ mile southwest of the discovery well, and was completed on February 4, 1928, with an initial production of 80 barrels per day. Several more producing wells, all of which were located nearly in line with the Smith well and the discovery well, were completed during the next few months.

On October 5, 1928, the Roberts No. 1, located ¾ mile southwest of the Smith well, blew in unexpectedly and was out of control for 14 hours, making about 50,000,000 cubic feet of gas per day with a spray of oil. Both geological and geophysical work indicated that this well was some distance away from the edge of the dome. On the supposition that Roberts No. 1 might be on a fault tangential to the edge of the dome,

location was made for A. E. Todd No. A-1 about 4,000 feet southwest of and in line with Roberts No. 1 and Smith No. 1. After the Todd well was completed on December 1, 1928, making 113 barrels per hour through a 5/8-inch choke, location for Purvey No. 1 was made 3,200 feet farther southwest. This well was completed on April 12, 1929, making 4,000,000 cubic feet of dry gas through a 3/8-inch choke.

Shortly thereafter, two wells were completed which disproved the fault theory and made the outlook for the field much less promising. On April 25, 1929, Gouger No 1, southwest of Purvey No. 1, tested salt water and on June 17, 1929, Todd No. A-2, which offsets Purvey No. 1 on the east, was drilled into salt at a depth of 3,587 feet without encountering Woodbine.

While this development was taking place, wells drilled on the northwest flank of the dome reached the Woodbine sand at favorable depths with no showing of oil. Wells drilled northeast of the discovery well, although favorably located, failed to find any Woodbine.

Drilling was concluded with the completion of Todd No. A-6 on May 24, 1931. Of a total of eighty wells drilled, six were completed as gas wells, thirty-three as oil wells, and forty-one as dry holes.

PHYSIOGRAPHY

Boggy Creek dome is located in that physiographic province known as the Nacogdoches Wold,[1] in which practically all of the interior salt domes of East Texas occur.

The topography in the vicinity of the dome is broken and hilly, characteristic of the outcrops of the Lower Claiborne formations. Hills on the east attain an elevation of nearly 700 feet, while the average elevation through the Neches River bottom approximates 300 feet. In the immediate vicinity of the uplift the maximum relief is about 180 feet.

Although unusual in shape and size, Boggy Creek has many of the physiographic features found on other interior domes. There is a low central area flanked by hills on the west and northeast. These hills are capped by greensand of the Weches formation and are remnants of a rim of hills which once surrounded the dome. A large portion of the central area is occupied by the flood plain of Neches River.

Near the east bank of the river, in the northwest corner of the N. Johnson survey, there is a small, elongated sand ridge which rises about 50 feet above the river bottom. A saline prairie, on which there are

[1] A. C. Veatch, "Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas," *U. S. Geol. Survey Prof. Paper 46* (1906), p. 29.

several small mud volcanoes, adjoins the sand ridge on the east and southeast. Honey Lake is located near the north end and Carey Lake near the south end of the saline. These lakes are crescent-shaped and resulted from abandoned meanders of the river. A spring showing gas and a trace of oil occurs in the edge of the river bed immediately south of the old bridge near Carey Lake.

Circular drainage outlines a considerable portion of the dome. Along the east and northeast edges Spring Branch flows in a northerly direction and empties into Neches River. The river, flowing in a general southerly direction, follows along the northwest and west flanks of the dome until it is met by Boggy Creek, which is flowing in exactly the opposite direction. At this point the river turns southeast and in crossing the dome makes a pronounced meander in the structurally low central area. The effect of the uplift upon the course of Boggy Creek is very marked. This stream flows in a normal southeasterly direction until it reaches the west flank. There it bends sharply to the north and flows a distance of two miles along the west edge of the dome before reaching the river.

SURFACE GEOLOGY

The surface beds of this general area belong to the Lower Claiborne group of the Eocene Tertiary. The areal geology and its relation to the outline of the salt mass are shown in Figure 1. The most interesting feature is the presence of Reklaw, Carrizo, and Wilcox in an area where normally the oldest formation exposed would be Queen City.

The oldest formation outcropping in this area is the Wilcox. Good exposures are limited because the greater portion of the top of the dome is overlain by recent flood-plain deposits of sand, silt, and conglomerate. Definite Wilcox sediments are found near the northeast corner of the N. Johnson survey and a probable outcrop occurs on the southwest bank of Carey Lake. Core tests located on top of the dome encountered this formation within a few feet of the surface. The Carrizo formation, which is predominantly sand, lies unconformably on the Wilcox and varies in thickness from 50 to 150 feet. The best exposure occurs on the south side of Carey Lake. As shown in Figure 1, the Reklaw outcrop outlines the main portion of the uplift but is absent over the narrow southwest extension of the salt mass. The Reklaw found here is of normal character and thickness. It is rather difficult to trace on the west and north sides of the dome, but some very good exposures can be found on the east side near Carey Lake. The Queen City formation crops out in the greater portion of the region, being composed of sands

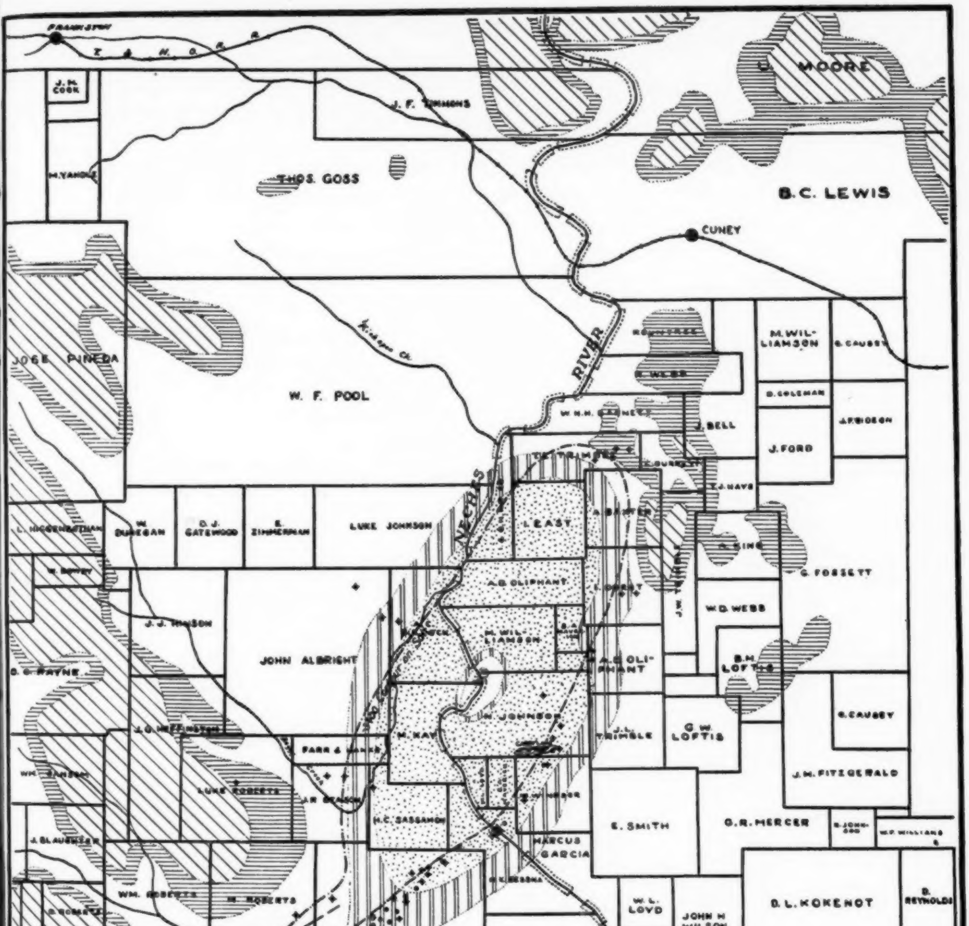
SURFACE GEOLOGY
BOGGY CREEK SALT DOME
ANDERSON AND CHEROKEE COUNTIES, TEXAS
SCALE 0 4000 8000 12000 FEET
SPARTA
WECHES
QUEEN CITY
REKLAW
RECENT, CARRIZO, & WILCOX
B.C. LEWIS
CUNEY
THOS. GOSS
J. F. TIMMONS
W. F. POOL
JOSE PINEDA
RIVER
NECHES
LUKE JOHNSON
JOHN ALBRIGHT
LUKE ROBERTS
WM. ROBERTS
A. B. PATTON
F. CUBIER
WM. WRIGHT
JOHN M. SCAGGS
A. BROWN
E. SMITH
G. R. MERCER
D. L. KOKENOT
JOHN H WILSON
JOS. CAMPBELL
MARCUS GARCIA
HENRY CHAPEL
J. J. VICKERY
C. H. SMITH
J. H. SHAW
ELISHA VICKERY
C. B. HUFFMAN
J. T. SOWELL
R. SMITHERS
J. M. GEORGE
G. W. LOFTIS
J. H. FITZGERALD
G. FOSSETT
W. D. WEBB
J. FORD
J. BELL
ANDERSON COUNTY
CHEROKEE COUNTY
I. & G. N. R. R.

Fig. 1

and sandy clays and having a thickness of about 350 feet. The Omen greensand member of the Queen City is poorly developed and outcrops are limited. The thickness of the Weches formation varies from 50 to 60 feet. Typical outcrops show laminated iron ore well developed at the top of the section. Exposures can be found over the southern extremity of the uplift and in the adjacent areas on the west and northwest. A few outliers of Weches also occur near the northeast and west edges of the dome. Weches and Queen City are found considerably below normal near the center of the dome in the northwest corner of the N. Johnson survey. The Sparta formation is composed of sands and light-colored sandy clays that produce a deep sandy soil. For a more complete discussion of the Lower Claiborne beds, reference is made to a previous paper.[1]

STRATIGRAPHY

The normal stratigraphic section in the vicinity of the Boggy Creek dome, as determined from wells drilled away from the upthrust, is shown in Table I.

Over most of the dome, anhydrite, varying in thickness from 10 to 140 feet, is found overlying the salt. In most instances, the salt[2] encountered has been relatively pure.

In addition to the Woodbine, horizons on the uplift which have had showings of oil are the Wilcox, Georgetown, and Glen Rose. Oil showings were obtained from the Wilcox in the Spencer Clemons core tests at depths of 85 to 160 feet and in Gouger No. 3 and other wells at depths of about 1,500 feet. In places the Georgetown is slightly porous and stained with asphalt. Reynolds Mortgage Company No. 2 tested 2 gallons of 21.6° Bé. gravity oil with basic sediment and water from this formation. Showings of asphalt were obtained from limestone of Glen Rose age in Earle and Ragsdale No. 3 and Spencer Clemons No. 2.

The relative thinning of beds over the salt is shown in the cross sections in Figures 3 and 4. In the upper beds the greatest thinning occurs in the Wilcox. The Pecan Gap is the oldest formation which has been present in every well on the uplift. Georgetown was found in Earle and Ragsdale No. 1, but no Eagle Ford or Woodbine has ever been encountered over the main portion of the dome.

[1] E. A. Wendlandt and G. M. Knebel, "Lower Claiborne of East Texas, with Special Reference to Mount Sylvan Dome and Salt Movements," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 10 (October, 1929), pp. 1350-61.

[2] A salt core from 3,907 to 3,916 feet, Earle and Ragsdale No. 3, showed 14 per cent potassium chloride with 8.8 per cent of this amount present as potassium.

TABLE I

STRATIGRAPHIC SECTION IN VICINITY OF BOGGY CREEK DOME

	Thickness in Feet	
TERTIARY		
Eocene		
Lower Claiborne group		
Sparta	0-50	Non-marine sands and sandy clay. Thin beds lignite
Weches	50-60	Marine glauconitic sands and clays capped by iron ore
Queen City	350	Largely non-marine, light-colored sands and sandy clays. Includes Omen member near base
Reklaw	120-130	Marine, glauconitic sands and sandstone and clay. Chocolate clays and brown sandy clay
Carrizo	50	Non-marine light-colored sand and sandy clay. Thin streaks lignite
	Unconformity	
Wilcox	1,500	Non-marine micaceous sand, sandy clay, and lignitic clay
Midway	1,200	Marine yellow and blue clays with sand streaks
	Unconformity	
CRETACEOUS		
Gulf		
Navarro (including Marlbrook) (uppermost Taylor)	500	Predominantly shale. Rather calcareous toward base. Nacatoch sand section absent. Marlbrook consists of dark calcareous shale
Pecan Gap (Upper Taylor)	400	Chalk, some calcareous shale breaks
Taylor (Lower)	500	Dark gray, blue and yellow calcareous shale. Wolfe City represented by sandy glauconitic zone
Austin	200	Hard chalk
Eagle Ford	130	Brittle dark gray shale and speckled shale
Woodbine	500	Predominantly sand. Thin beds of lignitic sand, sandy shale and red beds near top
	Unconformity	
(Comanche formations encountered on the uplift)		
Comanche		
Washita		
Washita shale	75-100	Brittle dark gray to brown shale
Georgetown	?	Hard light to dark gray limestone. Some breaks of shale and soft white limestone
Fredericksburg	?	Gray shale and hard gray limestone (identified only in Reynolds Mortgage No. 2)
Trinity		
Glen Rose	?	Hard dark gray limestone and oölitic limestone with streaks shale (identified only in Spencer Clemons No. 2 and Earle and Ragsdale No. 3)

The thickness of formations on the flanks can not be ascertained without making allowances for variations in dip. From subsurface data, the lower formations seem thicker in the north part of the field, but this is due to the steeper dip and not to actual thickening of the beds.

Since only three wells have been drilled off the edge of the uplift, little is known concerning the thickness of formations in the rim synclines. On the west, Hall No. 1 reached the Pecan Gap at a normal depth, while Coleman No. 1 had an abnormally thick section of Wilcox and reached the Pecan Gap about 100 feet below normal. At the north end, Weinberg No. 1 had a thickening of 200 feet or more in the Midway and was abandoned in the Navarro.

STRUCTURE

Surface.—In some respects this uplift has features similar to those found on other interior salt domes. The narrow outcrop of Reklaw is evidence of the steep quaquaversal dip around the periphery of the major portion of the salt mass. A Weches outcrop and core-test data show that the uplift has a central low area. Synclinal areas partially surround the dome, the deeper portions being toward the west and north. Faulting is present at the south end.

Weches elevations near the uplift range from 675 feet on the east to 334 feet on the north. Adjacent to the southeast flank of the structure, little surface-structure control is available, since outcrops are confined to unconsolidated Queen City beds.

Surface beds over the southwestern extremity of the salt have been affected by faulting rather than uplift. The main fault is nearly tangential to the northwest edge of the salt, having a strike approximately N. 32° E. Downthrow is toward the northwest, with a maximum surface displacement of 140 feet. The best exposure is near the southwest corner of the W. T. Todd 160-acre tract, M. Roberts survey. Another fault, having a general strike of N. 12° W. and with downthrow toward the east, extends across the extreme southwest end of the salt mass. Steep surface dips in the southeast part of the E. C. Woodham survey are probably due to this fault.

Subsurface.—Boggy Creek is unlike the typical interior salt dome because of its abnormal size, shape, and unusual structural features.

As shown in Figure 2, the salt core is elongated and has a promontory at its southwest extremity. The axis of the salt mass strikes about N. 28° E., being approximately parallel with the axis of the East Texas geosyncline. The main portion is elliptical in outline, being about 5

miles long and 1½ miles wide. The promontory on the southwest is 2 miles long and ½ mile wide.

The average sub-sea depth of the salt is about 2,000 feet in the main portion of the uplift and about 3,000 feet in the southwestern portion. The highest salt encountered was in Spencer Clemons No. 1 at a sub-sea depth of 1,829 feet. A depression in the salt possibly occurs near the center of the dome.

The Woodbine subsurface map shows that this formation has been found highest on the west side, in Spencer Clemons No. 2. It has never been encountered over the crest of the salt. In the productive area, on the southeast flank, the highest Woodbine was encountered in Tom Jones, Jr., No. 1, at a sub-sea depth of 2,885 feet. Northeast of this well the Woodbine gradually assumes a lower position on the flank until it is absent above what normally would be the water level. Reynolds Mortgage No. 2, northeast of the producing area, reached Georgetown at a sub-sea depth of 3,911 feet without encountering Woodbine. Near the south end of the oil-producing area, the Woodbine probably is not present above a sub-sea depth of 3,100 feet. At this end of the field this formation has a dip of about 12° and at the north end about 60°. On the southwest, the productive area is terminated by a northwest-southeast trending fault. The maximum displacement of the Woodbine is about 300 feet with upthrow toward the west. Only dry gas and a small amount of low-gravity oil have been produced on the upthrow side. The northeast-southwest trending fault at the south end of this dome is probably very pronounced in the Woodbine. In the vicinity of Stephenson No. 1, the displacement is at least 400 feet.

RELATION OF OIL AND GAS ACCUMULATION TO STRUCTURE

The relation between accumulation and structure may best be understood by referring to Figure 2, which shows the structure of the Woodbine. In the oil-producing area on the southeast flank, the highest pay sand is found at a sub-sea depth of 3,094 feet and the water level occurs at a sub-sea depth of about 3,370 feet. In the southern portion of this area, the upper Woodbine sand has never shown salt water. Lenticular sands may account for this condition. In the gas area at the south end of the dome the highest pay sand is found at a sub-sea depth of 3,007 feet and the water level at a sub-sea depth of 3,200 feet. About ¾ mile north of the gas area, Stephenson No. 1, on the west flank, encountered a good showing of oil in the Woodbine at a sub-sea depth of 3,014 feet, but tested salt water. The highest Woodbine was found on

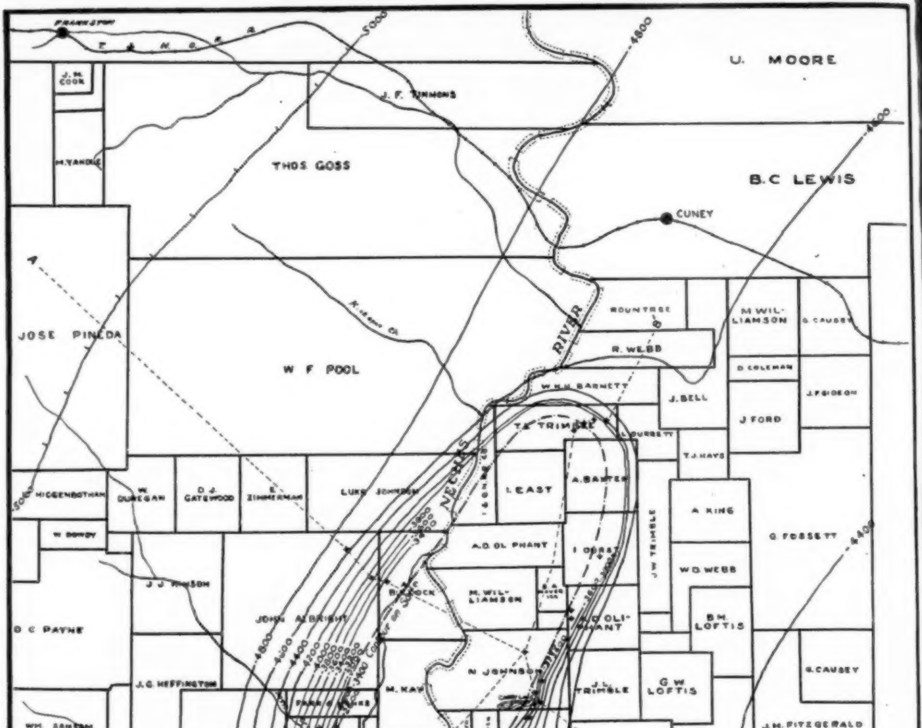

FIG. 2.—Woodbine structure map and key to cross sections. Boggy Creek salt dome, Anderson and Cherokee counties, Texas. Contour interval, 200 feet. Datum, sea-level.

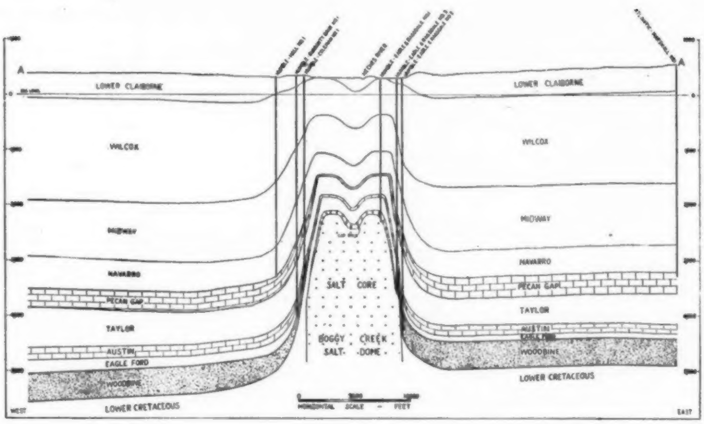

FIG. 3.—Cross section of Boggy Creek salt dome from northwest to southeast along line *AA'* of Figure 2, showing steep dip of formations on flanks and relative thinning over top of salt. Georgetown and all overlying formations, except Eagle Ford and Woodbine, are present on top of salt mass. Basis for showing syncline on top of salt is furnished by core-test information and areal geology. Earle and Ragsdale No. 1, on top of dome, encountered 140 feet of anhydrite overlying salt.

the west flank of the dome, in Spencer Clemons No. 2, at a sub-sea depth of 2,661 feet. The sand in this well had no showing of oil or gas.

As shown in Figure 2, the Woodbine formation is 400 or 500 feet lower structurally in the synclinal area west of the dome than immediately east of the dome, the regional dip being toward the west. There is also a rapid westward thickening of the lower Taylor, Austin, and Eagle Ford formations. Therefore, it might be assumed that oil migration in this area was toward the east and that there should have been some accumulation on the west side of the dome. Since oil is found only on the southeast flank, it seems logical to conclude that the Woodbine was structurally highest on this portion of the uplift during the time of accumulation and that the pronounced salt movement which elevated the Woodbine to its present high position on the west flank did not occur until after the period of migration.

A less plausible explanation for the absence of oil on the west flank is that the rim syncline on this side of the dome may have developed sufficiently at the time of migration to prevent any oil from reaching this flank.

The isolated dry gas area is without doubt due to the northwest-southeast trending fault. The low-gravity oil associated with the gas probably originated in the Lower Cretaceous and it is possible that the gas also came from this source. Another possibility is that the gas originally accumulated with the oil on the southeast flank and later migrated to its present position.

AGE OF DOME

Wells at Boggy Creek have furnished no information concerning the age of the salt except that it is probably older than Glen Rose. The presence of sedimentary salt in the Trinity in a well[1] in the Smackover field, Arkansas, indicates that salt at Boggy Creek and other interior domes may be Trinity in age.

Little is known concerning the early salt movement. The upthrust no doubt occurred contemporaneously with that of other East Texas domes. The movement has been progressive, probably beginning at some period in the Lower Cretaceous and continuing as late as post-Claiborne time.

The absence of Woodbine on top and the fact that the Georgetown has always been found higher on the flanks suggests that a Lower Cretaceous island existed here during Woodbine sedimentation.

Aside from the thickening of the Wilcox and Midway formations in the rim synclines, the only guide in determining the time of movement is the relative thinning of beds over the top of the salt. As shown in Figure 4, the relative thinning is about the same for all beds except the Wilcox. On the southwest promontory there was little or no upward movement during or after Wilcox time. On the main portion of the dome the most pronounced salt movement probably occurred between middle Wilcox and Carrizo times. Later salt movement, which occurred over the main portion after deposition of the lower Claiborne, was followed by subsidence of formations over the central portion of the salt mass.

OPERATING METHODS

Wells in this field were drilled by the rotary method. About two joints of surface casing and from 1,000 to 1,500 feet of 8-inch casing were set in most wells, because of the tendency of the shallow formations to cave. In all producing wells either 6⅝ or 7-inch casing was set and cemented on top of the Woodbine formation and 5 3/16-inch screen was set

[1]Lion Oil and Refining Company Hayes No. A-9 encountered rock salt at a depth of 5,974 feet and continued in salt with some streaks of anhydrite to its present depth of 7,255 feet.

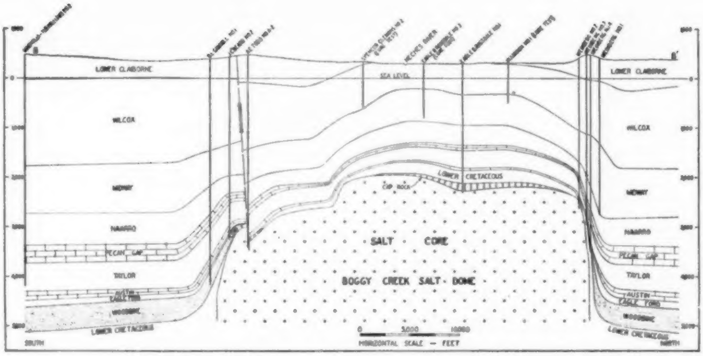

FIG. 4.—Southwest-northeast section through Boggy Creek salt dome along line *BB'* of Figure 2, showing northwest-southeast fault at southwest extremity and precipitous dip off northeast edge. Wilcox over southwest promontory shows much less movement than over main portion of uplift. Lower Claiborne beds over promontory are disturbed only by faulting, which probably occurred contemporaneously with post-Lower Claiborne upthrust at north.

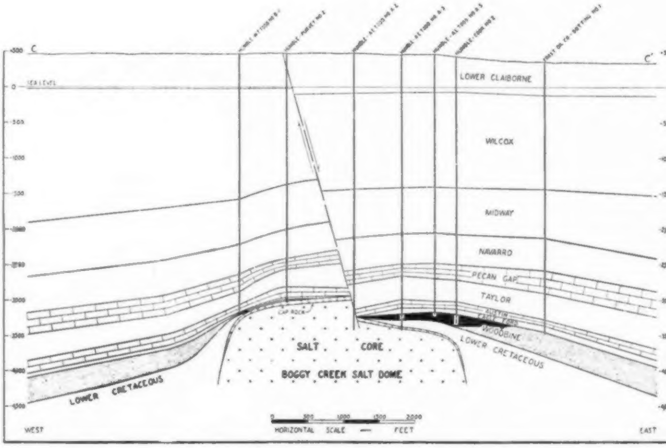

FIG. 5.—Cross section of Boggy Creek salt dome from northwest to southeast along line *CC'* of Figure 2, showing that Lower Claiborne beds have been affected only by faulting, while those below have been subjected to both uplift and faulting. Greatest amount of thinning has taken place in Pecan Gap and underlying beds. Woodbine and Eagle Ford are found on top of salt mass only in this locality.

through the pay sand. Producing wells were equipped with 2½ or 3-inch tubing and were brought in by washing or swabbing. Initial casinghead pressures varied from 60 to 1,200 pounds. On completion, most wells were placed upon a ⅜-inch choke, and as the pressure decreased, the size of the choke was gradually increased.

Plugging back wells to shut off water has not been satisfactory. Of seven wells plugged back, the water was completely shut off in only one. Deepening has been successful only in the southern end of the field where the lower Woodbine sand can be reached above water level. Wells deepened in other parts of the field encountered good oil showings in the lower sands, but tested salt water.

No crooked-hole surveys were made until about half of the wells were completed. In the north half of the field, where steep dips are encountered, wells have a maximum deviation of 20° off vertical. In the south end of the field, where the dips are not so sharp, the deviation off vertical ranges from 2° to 4°. In some localities it has been found practically impossible to drill a straight hole. In the case of the Neches River Stateland No. 1, which was plugged back and re-drilled, the second hole was found to be as crooked as the first.

PRODUCTION

On January 1, 1932, the total cumulative production for this field was 3,246,622 barrels. The average daily production was about 1,000 barrels, from twenty-eight producing wells. The peak in average daily production was 4,500 barrels, attained in March, 1929. Production decline during the past year has been very rapid.

The oil-producing area contains about 200 acres. It extends about 2⅔ miles in a northeast-southwest direction, being about 1,000 feet wide at the south end and gradually narrowing toward the north to a width of less than 100 feet. The production per acre, to January 1, 1932, amounted to about 16,000 barrels.

The oil produced from this field is similar in quality to that of other Woodbine fields. Its analysis follows.

Gravity	38.5° Bé.
Viscosity	40/100
Flash	R. T.
Sulphur content	0.24 per cent
Color	Green-black

The casinghead gas produced with the oil has a gasoline content of about 3.5 gallons per 1,000 cubic feet. Pipe-line outlet for the field is

furnished by the Humble Pipe Line Company's 8-inch line to Groesbeck. A refinery and casinghead gas plant are operated at the field by the Humble Oil and Refining Company. The refinery has a daily capacity of 4,500 barrels of oil. The casinghead gas plant has a daily capacity of 5,800 gallons of gasoline. The residue gas from this plant is utilized by the Dixie Gulf Gas Company.

A small gas area of about 50 acres occurs just southwest of the oil-producing district. In this area are four wells which had produced a total of about 666,000,000 cubic feet of gas up to September 1, 1931. This gas has a gasoline content of about 0.3 G. P. M.

W. T. Todd No. B-1, located on the northwest edge of the gas area, produced about 2,000 barrels of oil before being abandoned due to salt water. The oil produced from this well was different from that produced in the field proper, as shown from the following analysis.

Gravity	26.8° Bé.
Viscosity	100/100
Flash	R. T.
Sulphur content	1.11 per cent
Color	Black

Salt-water encroachment in the producing area has been very rapid. On October 1, 1929, the field as a whole was making 25 per cent water. During the early part of 1930 this amount increased to 50 per cent and by February 1, 1932, 85 per cent of the production of the field was salt water. During the latter part of 1931, gas wells in the south end of the field began showing water, and by February, 1932, all gas wells had been abandoned except two.

The only wells that have not been affected by salt water are on the A. E. Todd and Cook leases, near the south end of the field. Wells in this area have produced from the upper Woodbine sand until the oil was exhausted, and water has appeared only in those which have been deepened to the lower Woodbine sand or the Georgetown. Analyses of typical water samples are given in Table II.

From the present rate of production decline, it is believed that practically all wells in the north half of the field will be abandoned during the present year. The total ultimate recovery from the field will probably not exceed 4,000,000 barrels.

TABLE II

ANALYSES OF WATER FROM WOODBINE SAND FROM WELLS IN BOGGY CREEK FIELD

Radicals	*Botting No. 1* Depth 3,830 Feet*	*Earle and Ragsdale No. 2 Depth 4,229 Feet*	*Elliott and Clark No. 1 Depth 3,847 Feet*	*Elliott and Clark No. 1 Depth 3,847 Feet*	*John Gouger No. 1 Depth 3,955 Feet*
Sodium	29,322 P.P.M.	39,900	33,150	31,600	32,100 P.P.M.
Calcium	2,535	3,360	3,170	3,087	3,790
Magnesium	354	465	525	482	528
Chlorine	50,300	60,400	57,850	55,200	57,500
Sulphate	175	253	Trace	259	247
Bicarbonate	403	268	464	445	232
TOTAL	83,069	104,646	95,159	91,073	94,397
Comparison Data			*Per Cent*		
Primary salinity	89.22	88	87.8	87.8	85.84
Secondary salinity	10.32	11.6	11.8	11.74	13.92
Primary alkalinity	....	....	....	....	....
Secondary alkalinity	0.46	0.2	0.4	0.46	0.24
Chlorine salinity	99.7	....	....	99.7	99.6
Sulphate salinity	0.3	....	....	....	0.4
Ratios					
Chlorine: bicarbonate	215.0	....	....	213	426.0
Bicarbonate: sulphate	1.79	....	....	1.35	0.74
Calcium: magnesium	4.62	4.4	6.05	3.9	4.36
Sodium: calcium and magnesium	8.26	7.4	8.95	7.1	6.00

Radicals	*P. Holloway No. 1 Depth 3,767 Feet*	*P. Holloway No. 2 Depth 3,802 Feet*	*Mandelstam No. 2 Depth 3,814 Feet*	*D. Stephenson No. 1 Depth 3,383 Feet*	*Todd No. A-1† Depth 3,771 Feet*
Sodium	28,600	14,500	52,400	38,800	41,228
Calcium	3,075	136	3,136	4,850	4,376
Magnesium	447	70	432	619	889
Chlorine	50,500	22,400	59,000	69,900	73,800
Sulphate	161	189	15.6	286	None
Bicarbonate	287	360	427	244	171
TOTAL	83,070	37,665	115,410.6	114,699	120,064
Comparison Data			*Per Cent*		
Primary salinity	86.76	98.04	88.6	85.26	86.00
Secondary salinity	12.92	1.04	11.0	14.54	13.86
Primary alkalinity	....	....	....	....	....
Secondary alkalinity	0.32	.92	0.04	0.2	0.14
Chlorine salinity	99.8	....	100.0	99.97	100.00
Sulphate salinity	0.2	....	0.00	0.03	....
Ratios					
Chlorine: bicarbonate	303.0	....	237.71	493.00	743.28
Bicarbonate: sulphate	1.4	1.5	21.85	0.67	....
Calcium: magnesium	4.17	1.18	4.41	4.84	29.88
Sodium: calcium and magnesium	6.55	....	7.72	5.78	6.15

*Drilled by Frost Oil Company. All other wells drilled by Humble Oil and Refining Company.

†Water from this well is probably coming from the Georgetown limestone.

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GEOLOGICAL NOTES

SALT IN SMACKOVER FIELD, UNION COUNTY, ARKANSAS[1]

The Lion Oil and Refining Company's Hayes well A-9, Sec. 4, T. 16 S., R. 15 W., is located near the top of the Norphlet dome, Smackover field, Union County, Arkansas. This well encountered rock salt at 5,974 feet and is now temporarily shut down in rock salt at a depth of 7,255 feet.

The presence of salt beneath the oldest known Comanche strata of this region has naturally suggested the possibility that Smackover is a salt dome. It is the purpose of the writer to discuss this possibility.

STRATIGRAPHY

The Tertiary and Upper Cretaceous strata overlying the area of the Smackover field, except for some thinning in the basal Upper Cretaceous beds, do not depart from the normal stratigraphic section of this region. The Upper Cretaceous is separated from the underlying Comanche strata by a pronounced unconformity which has truncated these strata from west to east. The Comanche series of this region is divided as shown in Table I.

TABLE I

SECTION OF COMANCHE SERIES IN ARKANSAS

Comanche Series	*Thickness in Feet*
Washita group Fredericksburg group } undifferentiated	0- 400
Trinity group	
Upper Trinity (Paluxy) Upper Glen Rose }	0-1,700
Anhydrite zone	0- 600
Lower Glen Rose	0-1,000
Lower Trinity red series	1,800-2,300
Trinity group ?	
Lower Marine series	800+
Basement rocks not reached in basin	

In the Norphlet district of the Smackover field, wherein the Lion Oil and Refining Company's Hayes well A-9 is situated, the basal Upper Cretaceous lies directly on the Lower Trinity red series, the remainder

[1]Read by title before the Association at Oklahoma City meeting, March 25, 1932. Manuscript received, April 6, 1932.

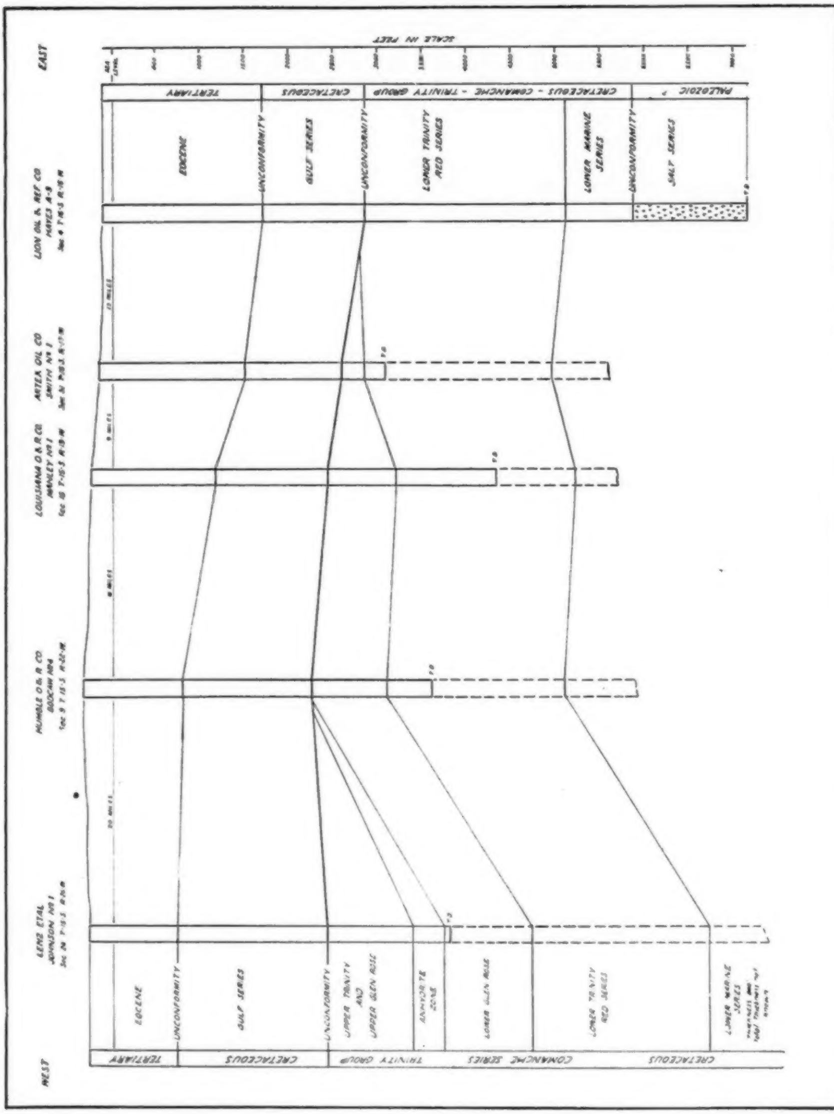

FIG. 1.—Generalized west-east well section from Miller County into Smackover field; showing stratigraphic relationship of Upper and Lower Cretaceous.

of the Comanche series being absent, the result of truncation in the interval of erosion between the end of the Comanche and the beginning of the Upper Cretaceous.

The Lower Trinity red series, as recorded in the deep well from 2,953 to 5,220 feet, a thickness of 2,267 feet, exceeds by more than 350 feet the maximum thickness recorded for this series in deep wells drilled elsewhere in Arkansas and northern Louisiana. The basal 300 feet of these beds as recorded in the Smackover well contains more calcareous materials than have been found in this member elsewhere. The Marine series from 5,220 to 5,974 feet differs in lithology from the Lower Marine series as recorded in deep wells drilled in the Bellevue, Pine Island, and Homer fields, in Louisiana, in that they contain more Marine limestone and chalk and less shales and sands. These facts suggest the possibility that the lower part of the red series in the deep Smackover well may represent a near-shore facies of the upper part of the Lower Marine series as recorded in the deep wells referred to above, and the marine beds recorded in the Smackover well may represent a horizon not reached in other deep wells. The contact between the Marine series and the underlying salt was not adequately cored, but from its lithology suggests an unconformable contact with the salt, or an intrusive contact.

SALT SERIES

The salt penetrated from 5,974 to 7,255 feet, a thickness of 1,281 feet, is remarkably pure, containing only thin lenses of anhydrite, and, as contrasted with known salt series throughout the world, is not a normal saline series. The contact of the salt with the overlying marine limestone suggests salt movement. The age of the salt is not determinable, but the probability that it is older than Comanche is suggested.

STRUCTURE

A conspicuous feature of the basement floor upon which the Comanche sediments accumulated is a pronounced flexure which extends from southern Little River County eastward into Calhoun County and thence southeastward into Louisiana. North of the flexure the Comanche sediments are of nominal thickness; the Lower Marine series is absent, and deep wells reach the underlying basement rocks at a nominal depth. South of the flexure, wells many hundreds of feet deeper have failed to reach the basement rocks. The rate of dip of the flexure is not known, but it is indicated by deep wells to be more than 300 feet per mile toward the south and southwest, and probably much steeper.

FIG. 1.—Generalized west-east well section from Miller County into Smackover field; showing stratigraphic relationship of Upper and Lower Cretaceous.

It seems probable that this inferred flexure may actually be a fault in the basement rocks which as a structural feature limited the landward extension of the Lower Marine series and within narrow limits determined the strand line of the Comanche sea at least in Trinity time.

At the close of the Comanche, the sediments were uplifted and, in the area of the Smackover field, were tilted toward the west and southwest, as now evidenced by the prevailing southeasterly strike through southeastern Arkansas and northern Louisiana. The evidence further indicates that the upward movement was most intense along a line parallel with the inferred sharp flexure fault in the basement rocks. The structure of the Comanche strata is not readily determinable in this area for the reason that the red series immediately below the base of the Upper Cretaceous lacks beds recognizable from well to well. The contact between the Lower Glen Rose and the Lower Trinity red series, however, is irregular in the area of the Smackover field, indicating differential movement which may total 150 or 200 feet. The thickness of the Lower Trinity red series in the Smackover field, on the other hand, precludes differential movement during the deposition of these strata.

The Norphlet dome as mapped on the Graves sand is a roughly circular dome, about 4 miles in diameter, with a closure of between 60 and 70 feet.

The regional structure suggests that the sharp flexing or fault in the basement rocks influenced the structural alignment in the Comanche strata, and that movement along this line continued into Upper Cretaceous time, expressed in southeastward trending anticlines, which were modified in outline by later Cretaceous and Tertiary warping. There is thus a suggestion that the line of sharp flexing or faulting in the basement rocks was an active line of weakness, the influence of which persisted well into Cretaceous time.

The structure of the Smackover field, as determinable from deep wells drilled to date, is not suggestive of salt movement.

CONTACT OF SEDIMENTARY SECTION WITH SALT SERIES

In the deep Smackover well, the salt is overlain by 20-30 feet of shale mixed with limestone and salt and containing some red clay, above which are marine limestones of Comanche age. In the normal sedimentary section in which salt beds occur, the salt strata do not constitute the top of the saline section, but are overlain by non-fossiliferous salt clays or shales containing salt crystals, to a thickness of the order of 250 feet or more. The existing relationship between the salt section and

the overlying sediments in the Smackover field is indicative of an unconformity at the top of the salt section or an intrusive contact of the salt into the Comanche series.

AGE OF SALT

The geologic and climatic conditions existent during the Comanche were not favorable to the formation of a thick salt series in this region. The history of the early Mesozoic is not well known, but probably was principally a period of denudation during which this region was reduced to a peneplain and does not appear to have been a favorable time for salt formation.

The Permian history of this region, although no better known than the early Mesozoic, was a world-wide salt-forming period as well as a period of active crustal movement and seems the most logical age for the salt in the Smackover field, as well as for the salt in the interior salt-dome region of northern Louisiana, which perhaps is co-extensive with the Smackover area.

SMACKOVER—A SALT DOME

That Smackover is a salt dome is naturally suggested by the purity and great thickness of the salt, and the relationship of the salt series to the overlying Comanche strata. These evidences are not conclusive proof of salt intrusion into the Comanche, but may with equal reason be ascribed to a pre-Comanche salt movement followed by erosion prior to Comanche sedimentation.

The structure of the Smackover field as determinable in the Cretaceous and Tertiary strata does not argue for salt intrusion into the Comanche. In fact the stratigraphic evidence indicates that there was no differential movement during the accumulation of the Comanche strata penetrated by the drill in this area, which contrasts with the Bellevue dome in Louisiana, where the Trinity shows a thinning of several hundred feet as the result of upward movement of the dome during deposition.

The available data suggest that the salt of indeterminate age could have been intruded in the Lower Marine series of the Comanche, but if so, the salt movement ceased prior to the deposition of the Lower Trinity red series. An alternate interpretation assumes an original salt series of Permian age which was deformed prior to Comanche time, probably forming salt anticlines with a southeasterly trend, parallel with the flexure or fault in the basement rocks, which during the erosion interval

prior to Comanche time were truncated, exposing the salt along the axes of the fold. This interpretation is developed in more detail in the following paragraphs.

TABLE II

TENTATIVE INTERPRETATION OF SECTION IN LION OIL AND REFINING COMPANY'S HAYES WELL A-9, SMACKOVER FIELD

	Depth in Feet
Tertiary-Eocene	0-1,860
———*Unconformity*———	
Cretaceous-Gulf series	1,860-2,953
———*Unconformity*———	
Cretaceous-Comanche series	
Trinity group	
Lower Trinity red series	2,953-5,220
Trinity group ?	
Lower Marine series	5,220-5,974
———*Unconformity*———	
Paleozoic-Permian ?	
Salt series	5,974-7,255+

If it is assumed that the sharp flexing in the basement rocks is a fault, then it must also be assumed that it is a normal fault with the downthrow toward the south and southwest. A fault of this type would be genetically related to the uplift of the Ouachita Mountains, a later event in the orogenic history which followed the lateral compression and overthrusting. The magnitude of the deformation permits the assumption that the fault as originally developed may have been of a high order of magnitude, sufficient to have produced a depression which permitted the Permian sea to invade this region, and as the movement continued, to allow the accumulation of a thick series of sediments including the salt series of which the salt in the deep Smackover well is a part.

The period between the uplift of the Ouachita Mountains and the beginning of Comanche sedimentation represents a long period of time and involves a complex series of geologic events which includes deposition of the salt series, deformation, erosion, culminating in the completion of the Ouachita peneplain and finally warping of the peneplain, permitting the transgression of the Comanche sea over this region.

The preservation of any part of the salt series after the long period of erosion prior to Comanche sedimentation may seem an improbable condition. However, if the assumption of the existence of a fault is granted, it must also be granted that it continued as an active line of weakness which the evidence indicates persisted into the Cretaceous. There could then have been a considerable lowering of the Permian

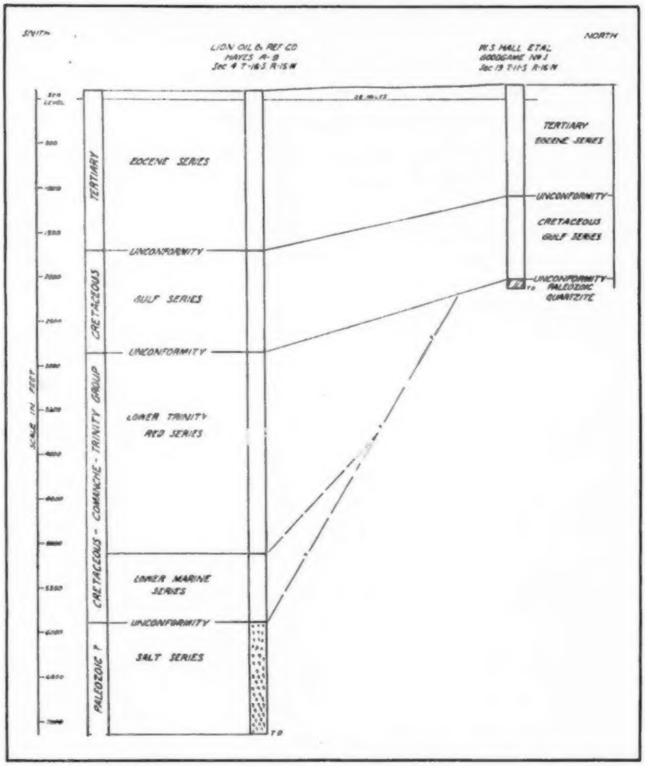

FIG. 2.—Generalized south-north well section showing relationship of Paleozoic basement rocks to salt series and overlying Lower Cretaceous in deep Smackover well.

sedimentary column, sufficient to preserve at least a part of the salt series from erosion.

It seems probable that in the interval between the end of Permian and the beginning of Comanche sedimentation, this region was subjected to differential folding, sufficient in magnitude to produce salt flowage and the development of salt anticlines adjacent to and parallel with the active fault in the basement rocks. Before the completion of the Ouachita peneplain, such anticlines may have been truncated, exposing the salt along the axes of the fold.

The downwarping of the Ouachita peneplain which permitted the transgression of the Comanche sea over this area appears to have hinged

on the assumed fault in the basement rocks, limiting the deposition of the Lower Marine series to the seaward side of this line of weakness. With this condition in mind, together with the fact that the lands bordering the Comanche sea were of low relief, it seems not improbable that the contact of the Lower Marine series with the salt in the deep Smackover well may be a normal contact between the Lower Marine series and the underlying truncated erosion surface of pre-Comanche age.

W. C. SPOONER

SHREVEPORT, LOUISIANA
April 6, 1932

CATAHOULA-FLEMING CONTACT, VERNON PARISH, LOUISIANA

The accompanying map (Fig. 1) shows the Catahoula-Fleming contact in Vernon Parish, Louisiana, as interpreted by the writer, who realizes that the area covered is one concerning which there is great diversity of opinion. This contact is here shown in greater detail than the original mapping by A. C. Veatch.[1]

These formations, the Catahoula and the overlying Fleming, make up the Miocene in western Louisiana. The Fleming corresponds with the Hattiesburg and the Pascagoula of Mississippi and Alabama, and is overlain by the Citronelle of Pliocene age.

Interest is taken in this general area because it lies between the production of northern Louisiana and the production of coastal Louisiana. The dry hole of the Exchange Petroleum Company (White-Grandin No. 1) in the SW. ¼, NE. ¼, SW. ¼ of Sec. 29, T. 3 N., R. 7 W.,

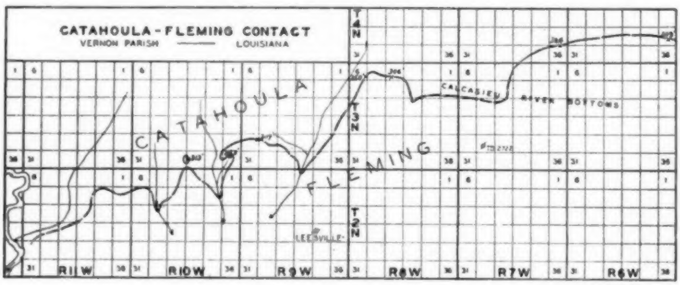

FIG. 1

[1] A. C. Veatch, "Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas," *U. S. Geol. Survey Prof. Paper 46* (1906).

reached the base of the Catahoula, which is also the base of the Miocene, at 1,757 feet.

In fixing the contact, the writer has used the presence or absence of calcareous material as the principal determining criterion. Noncalcareous clays were mapped as Catahoula; calcareous clays, in places also bearing many small white calcareous nodules, were mapped as Fleming. Other criteria were helpful, but the one mentioned was most readily applied in the field. At the places shown on the map by crosses, the contact is definite enough to enable one to determine the elevation as shown.

FRED M. HAASE

KANSAS CITY, MISSOURI
April 8, 1932

VICKSBURG FORMATION IN DEEP TEST, ACADIA PARISH, LOUISIANA

The Yount-Lee Oil Company has temporarily abandoned its Houssiere-Latrille No. 10 in the Jennings field, Acadia Parish, Louisiana, 5,435 feet east and 1,070 feet north of SW. cor. of Sec. 47, T. 9 S., R. 2 W., in a sandy shale at a depth of 8,633 feet. The well was drilled to a depth of 8,762 feet. Heaving shale was encountered from 8,663 feet to 8,755 feet and further drilling or coring of the hard sand logged from 8,755 feet to 8,762 feet was made practically impossible by the continual heaving-in of the overlying shale, finally necessitating a "back-up" to 8,633 feet to set screen.

This well is interesting from a paleontological standpoint, because the Vicksburg formation, Lower Oligocene, was penetrated.

The Miocene-Oligocene contact is estimated to be at a depth of 7,177 feet. There are no core samples from 7,031 feet to 7,445 feet, which unfortunately deprived the company of a correct paleontological contact; however, the estimation seems to be nearly accurate. In the Texas Company's Rayne Heirs No. 5, approximately 2,300 feet, 45° SW. from Houssiere-Latrille No. 10, the contact is drawn at 7,294 feet, a difference in depth of the Miocene-Oligocene contact in the two wells of 117 feet. The accuracy of the estimated contact in the Houssiere-Latrille well No. 10 is illustrated in the fact that the *Heterostegina* limestone zone in The Texas Company's well was found at 7,575 feet and in the Yount-Lee Oil Company's well at 7,459 feet, a difference in depth of the *Heterostegina* limestone zone in the two wells of 116 feet, or, specifically, in the former well, the thickness of the formation from the Miocene-Oligo-

cene contact to the *Heterostegina* zone is 281 feet, and in the latter well, 282 feet.

This 282 feet of formation overlying the *Heterostegina* zone is correlated with the *Discorbis* zone. The only cores obtained from this zone are from 7,445 to 7,446 feet, immediately above the *Heterostegina* zone. The cores were of gray, very hard and well cemented, calcareous sandstone and gray, calcareous, friable shales, and the residue consisted of fine to medium-grained quartz, chert, magnetite, abundant pyrite, siderite, gray shale, shell fragments, sponge spicules, and typical *Discorbis* zone *Foraminifera*.

The *Heterostegina* zone was found at 7,459 feet, the core at that depth being a gray, sandy limestone with numerous *Heterosteginoides* sp. This zone extends to 7,604 feet, a thickness of 145 feet of limestone, sandy, calcareous clays, and shales.

Below the *Heterostegina* zone are 512 feet of greenish gray, calcareous sandy shales and non-calcareous packed sands which are correlated with the *Marginulina* zone. The cores obtained were mostly sands and the foraminifers collected from the few shale cores were of no definite diagnostic value.

The Middle Oligocene-Vicksburg contact is drawn at 8,116 feet. Calcareous clays, sandy shales, and calcareous sandstones with typical Vicksburg *Foraminifera* are found in this zone from 8,116 to 8,633 feet. The Frio formation is absent in the area.

M. T. Halbouty

Beaumont, Texas
March 29, 1932

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 6 (JUNE, 1932), PP. 611-612

DISCUSSION

AGE OF PRODUCING HORIZON AT KETTLEMAN HILLS, CALIFORNIA

CORRECTION

In reproducing the authors' "Table I"[1] a slight omission was made. If uncorrected, this omission may make the table slightly misleading.

On the left-hand margin of Table I, a short horizontal line should be drawn below the marginal word "Monterey" and opposite the dotted line of the first column which separates the "*Valvulineria californica* zone" and the "'Monterey shale' between *V. californica* zone and 'Button bed' sand." With the table corrected in this manner, there is no implication that the 250 feet of beds above the Button bed, in the Chico-Martinez Creek area, are equivalent to any portion of the Monterey formation. Despite the fact that these 250 feet of beds are not included in the type sections of either the Monterey formation or the Temblor formation, the authors incline toward grouping them in some way with the Temblor formation because of faunal affinities of these beds with the upper Temblor.

Discussions among geologists and paleontologists concerning the 250 feet of beds mentioned in the preceding paragraph are increasing. An example can be seen in the recent paper by M. F. Keenan,[2] in which the following statement is made.

> Mr. Robert M. Kleinpell and Dr. Hubert G. Schenck were kind enough to check over this group of fossils (list given) and both agree that the stratigraphic position of the beds containing them is below the *Valvulineria californica* zone of the type Monterey formation and probably above, rather than below, the "Button Bed" of the Temblor formation at its type locality along Carneros Creek, in Kern County, California.

In Table I, the authors stated that this division is "appropriately called Gould shale member of Temblor." As used in this casual manner, the name has no standing in geologic time classification. In view of the importance of the unit, it is now proposed to define the name and to designate a type section for the beds involved.

The Gould shale is described as the 220 to 230 feet of beds overlying the Button bed member of the Temblor formation and underlying the *Valvulineria californica* zone of the Monterey formation near the center of the west half of Sec. 14, T. 29 S., R. 20 E., M. D. B. L. & M., and continuing to the southeast

[1]George M. Cunningham and W. F. Barbat, "Age of Producing Horizon at Kettleman Hills, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 4 (April, 1932), pp. 418-19.

[2]Marvin Francis Keenan, "The Eocene Sierra Blanca Limestone at the Type Locality in Santa Barbara County, California," *Trans. San Diego Soc. Nat. Hist.*, Vol. 7, No. 8 (1932), p. 69.

side of Chico-Martinez Creek, Kern County, California. The name is derived from Gould Hill appearing on the United States Geological Survey McKittrick Quadrangle, near the type locality.

W. F. BARBAT

BAKERSFIELD, CALIFORNIA
April 29, 1932

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 6 (JUNE, 1932), PP. 613-618

REVIEWS AND NEW PUBLICATIONS

"Das Erdölvorkommen von Volkenroda" (The Volkenroda Oil Field, Thuringia, Germany). By HELMUTH ALBRECHT. *Zeits. Kali, verwandte Salze und Erdöl* (Halle a.S.), Vol. 26, Nos. 3 and 4 (February 1 and 15, 1932), pp. 25-33, 39-43, 10 figs., 1 pl. with cross sections, and 1 pl. with 11 microphotographs.

This treatise contains the first authentic report on a recently discovered oil field in Germany. There are two features about the Volkenroda field which make this extremely interesting to the American reader. 1. Geological conditions in the new field resemble very closely those encountered in the Permian salt basin of West Texas and New Mexico. The discovery of the Volkenroda field, lying far out of the North German salt-dome oil province, has opened a new oil province for prospecting: the Permian salt basin of central Germany. This part of Germany has been held by most geologists to be barren of oil. 2. Production methods in this field are unique in that there are no derricks on the ground, the whole production being secured below the surface from bore holes drilled from the galleries of a large potash mine which is 3,300 feet deep.

Discovery of the field was made neither by geophysical nor geological methods, but accidentally in the process of the mining operations for potash salts. The potash company owning the Volkenroda mine had sunk three shafts, each about 3,300 feet deep, near Menteroda, about 7½ miles north of the city of Muehlhausen, Thuringia, central Germany. In this mine the mining of potash salts has been going on since 1909, the main object being a potash bed 15-30 feet thick consisting of sylvite and carnallite.

The shafts, which are about 2.3 miles apart, are interconnected underground by an elaborate network of levels, galleries, and workings, totalling several miles in length. The area explored by the workings of the mine is about 3.1 miles long and 1 mile wide.

On June 2, 1930, a gas blow-out occurred in one of the galleries at a depth of about 3,300 feet below the surface. Petroleum odor had been noticed some time before. The gas exploded, becoming ignited by the lamps of the miners. When the site of the explosion was investigated, oil and gas were observed seeping through several fissures from the rocks below the potash bed. The oil seeping out amounted to about 50 barrels daily. On September 18 and October 24, 1930, other gas blow-outs took place about a mile away from the first. These blow-outs were followed by much larger oil seepages than the first. They yielded about 400 barrels daily. It was now decided to drill a test hole about 1,000 feet away from the last encountered large seepage. This hole struck oil at about 150 feet below the floor of the gallery, that is, at about 3,450 feet below the surface. This was the beginning of oil production on a commercial scale. Since then more than 100 wells have been drilled, all of which have been cored.

The rocks cropping out in the vicinity of the Volkenroda mine are of Triassic age. The age of the potash bed is Upper Zechstein (Zechstein-Upper Permian). The rocks encountered in the holes drilled for oil below the potash bed are as follows.

	True Thickness in Feet
1. "Older" rock salt	88-147
2. "Basalanhydrite"	26-65
3. "Hauptdolomit" (Main dolomite)	110-210

The Hauptdolomit belongs to the uppermost part of the Middle Zechstein. It is the oil reservoir rock at Volkenroda. The Hauptdolomit is a dolomite consisting of 54-57 per cent of $CaCo_3$ and 42-44 per cent of $MgCO_3$. Its color shows all shades from light chocolate brown to deep black. The texture is usually uniformly dense. The uppermost part, however, is oölitic. The oölites show under the microscope crystals of anhydrite as centers surrounded by many concentric shells of dolomite. The author illustrates this and other interesting lithological features by a series of excellent microphotographs.

The oil is not confined to a distinct zone within the dolomite, but occurs from its top to its base. To a small extent the bedding planes produce oil. Transverse joints and cleavages contain most of the oil. The oil penetrated from these joints at some places into bedding planes and into smaller fissures forming "oil joints" and causing the black color of the whole dolomite mass. The joints strike almost perpendicularly to the strike of the strata and dip almost vertically. This is the reason why a large percentage of the bore holes have been drilled diagonally at an angle of 45°, so as to intersect the largest possible number of joints. Cores showing "oil joints," open joints, and those filled by rock salt are shown in photographs illustrating the article.

Many productive and dry wells are close together; for example, the most prolific well to date is only 260 feet from an almost dry hole. At another place one vertical and five slanting holes (less than 45°) have been drilled, radiating like beams of a star in various directions. Three of these holes struck oil, one encountered gas with oil traces, and two were dry holes.

The mining operations for potash revealed that the structural conditions underground are much more complicated than anticipated from the surface control. Two anticlines form the main feature, striking east and west and plunging eastward. The flanks of these anticlines have a dip of about 4°. The southern flank of the southernmost anticline has three minor anticlines superimposed. One of them is marked by sharp folding and overturning toward the north. A large fault zone, the Schlotheim fault zone, is known to extend near the southernmost of these minor anticlines. South of the fault zone lies a third major anticline. Productive wells have been drilled so far on the flanks and crests of the major anticlines only.

Very little is known as to the structural and geological conditions below the Permian salt series. The author holds the view that the oil did not originate in the Hauptdolomit, where it is found, but probably came from the Stinkschiefer, a bituminous shale facies of the Middle Zechstein, 20-40 feet thick, which grades laterally into the Hauptdolomit. The Stinkschiefer must not be confused with the well known Mansfield shale of the Lower Zechstein.

The maximum length of the bore holes is 340 feet. The diameter of the holes is 1½, 2⅝, or 3⅝ inches. All holes are cored by electrically driven diamond core-drilling machines. All of the wells are flowing. Three-fourths-inch tubing is set above the "pay." The wells are partly choked in. The closed-in pressure of the wells is between 284 and 1,137 pounds per square inch. The oil-gas ratio is about 1,400-1,700 cubic feet of gas per barrel of oil. Each well has its own gas separator underground. The oil is run through pipe lines to gathering tanks in the mine. It is pumped by two electrically driven triplex plunger pumps through one of the shafts to the surface. The gas goes up through a pipe line through another shaft. Potash-mining operations are carried on during the day shift and oil-development work during the night shift.

The author thinks that ultimate oil recovery by drilling small holes from the galleries will be much larger than by drilling wells from the surface. Total oil production of the mine during 1931 was 51,555 metric tons, equivalent to about 386,700 barrels of oil.

The oil is of 37.8° A. P. I. gravity at 68° F. Viscosity is 1.4 (Engler) at 68° F. The paraffine amounts to 1.94 per cent. Fractional distillation gave the following results.

Initial boiling point: 37° C.

Degrees C.	*Volume Per Cent*
To 100	12.0
To 150	25.0
To 200	35.0
To 250	45.0
To 300	58.0
More than 300	42.0

The oil is shipped by tank cars 75 miles to the hydrogenation plant of the I. G. Chemical Combine at Leuna. An analysis of the gas is as follows.

		Per Cent
CH_4	Methane	54.5
C_2H_6	Ethane	12.4
C_3H_8	Propane	9.0
C_4H_{10}	Butane	3.7
C_5H_{12}	and plus	2.2
N_2	Nitrogen	18.0
O_2	Oxygen	0.1
CO	Carbon monoxide	0.0
H_2S	Hydrogen sulphide	0.0
		99.9

Most of the gas is fired under boilers for local use, but plans are under way for building a natural gasoline plant.

Burbach Kaliwerke A. G., which owns and operates the Volkenroda mine, controls the oil and gas rights around the Volkenroda mine. The total area under control includes more than 22,000 acres.

Since there are, or have been, in operation more than 200 potash mines in Germany, many of which had distinct oil and gas showings which generally had been neglected, the search for oil in the Permian salt basin of central Germany will receive an important stimulus through the discovery of the Volkenroda field.

WALTER KAUENHOWEN

BERLIN, GERMANY
April, 1932

"Some Aspects of Electrical Prospecting Applied in Locating Oil Structures." By LEO J. PETERS and JOHN BARDEEN. *Physics*, Vol. 2, No. 3 (March, 1932), pp. 103-22.

This paper is concerned chiefly with developing the mathematical theory of electrical methods of investigating geological structure. The methods are classed in two groups, namely, (1) direct-current methods and (2) electromagnetic methods, each of which is discussed in considerable detail. There are in earth materials three variables capable of measurement by these methods, namely, (1) resistivity, (2) dielectric constant, and (3) magnetic permeability. The first, because of its wide range of variation, is best adapted for electrical methods of prospecting. Some of the conclusions are that by these methods oil can not be directly located, but geologic structure may be interpreted to a depth of 1,500-2,000 feet; that obscure surface faults may be detected, but truncated inclined beds may give rise to false interpretation of faults due to great differences in resistivity of two adjacent beds; and finally, that future improvements in field technique and methods of interpretation should open up a very definite field of usefulness for electrical methods of prospecting. The chief value of such methods lies in the fact that the forces can be absolutely controlled and the reactions accurately measured.

Physics is one of the publications of the American Physical Society. Editor, John T. Tate, University of Minnesota, Minneapolis, Minnesota.

R. W. CLARK

PITTSBURGH, PENNSYLVANIA
May 3, 1932

Leitfaden der Tiefbohrtechnik (Guide to Deep-Drilling Technique). By PAUL STEIN. (Julius Springer, Berlin, 1932). 52 pp., 61 figs. Price, RM. 4.20.

This well illustrated booklet furnishes an interesting account of the drilling technique used in different parts of the world. Its scope may be illustrated by a list of the subjects treated in the different chapters. I. Classification and designation of deep borings according to the purpose of the work. II. Power; dry- and wet-drilling. III. General account of surface equipment. IV. Classification and description of drilling methods. V. Casing and cementing. VI. Interruptions in drilling; fishing methods. VII. Drilling crews and accessory devices. VIII. Oil-well drilling and oil production.

The present small volume is a revised and improved third edition of one first published in 1905. That it has been brought thoroughly up to date is indicated by the fact that it contains discussions of crooked holes, coring devices, core-orientation, modern rotary-drilling, and geothermal measurements. It will give the oil geologist or engineer an opportunity to brush up on his German while acquiring some useful information.

R. D. REED

LOS ANGELES, CALIFORNIA
May 4, 1932

El Petroleo en Mexico. Bosquejo Historico (Petroleum in Mexico—Historical Sketch). By EZEQUIEL ORDOÑEZ. Reprinted from *Revista Mexicana de Ingenieria y Arquitectura* (Mexico, 1932). vii + 106 pp. $6\frac{1}{4} \times 8\frac{3}{4}$ inches.

The antiquity of the knowledge of petroleum, whether in solid, liquid, or gaseous form, and its use in early historic time from Peru to Babylon are discussed. A chapter is devoted to the nature and mode of occurrence of oil seepages in Colombia, Mexico, and Venezuela. Oil shale deposits in the United States are mentioned, and the probability of similar deposits existing in Chile on the flanks of the Andes. The importance of natural manifestations of petroleum is pointed out.

The historical aspect in Mexico begins with a discussion of archeological remains found in various parts of the oil regions; mention is made of drilling rigs being erected over such relics. A quotation from the historic work of the padre Sahagun regarding his reference to "chapuputli" is of interest (chapapote is the term used to-day for oil and asphalt). Attempts to exploit asphalt in 1865 are alluded to, leading to the initiation of the petroleum industry with the acquisition by E. L. Doheny of properties in the year 1900. Sir Weetman Pearson (Lord Cowdray) is referred to as the second discoverer of oil in Mexico on April 3, 1904, at Ebano; the development of such fields as Dos Bocas, Casiano, Potrero del Llano, Pánuco, and the Isthmus of Tehuantepec, is taken up. Installation of pipe lines and refineries is dealt with. Full development of the "Golden Lane," the increase of production from 1916 to 1920, and the rapid decline of production since 1923 are referred to. Among causes for the decline, difficulties between the Government and the companies, and the resulting almost complete cessation of the search for new pools are stated. World over-production is considered a contributing factor. A picturesque account of living conditions in Zacamixtle at the time of the oil boom will be appreciated by those familiar with conditions at that time.

In the final chapter the author discusses the difficulties of the geologists during early exploration, and the better conception of conditions after the lapse of time. Mention is made of various authors who have contributed to the literature on the geology of the oil regions. Lament is made that when all is considered very limited information is available, and even that consists of no little repetition. He believes that the true nature and conditions governing accumulation of petroleum in Mexico have not been thoroughly studied, and that a correct understanding of the subsurface structural features between the

Sierra Madre and the Gulf of Mexico would be of great importance for future developments in the search for oil.

The fact of Sr. Ordoñez having been associated, since the beginning, with the petroleum industry in Mexico, as a geologist, gives his treatment of the subject considerable weight. It is believed that a better understanding of subsurface conditions is known to the geological departments of some of the operating companies than the author appears to give credit for. Many problems yet remain to be worked out. Reference is made on page 10 to the discovery of a producing sector in Cacalilao by drilling in the vicinity of a gas seepage; those familiar with the district will recollect the bringing in of the first wells on the Rich-Mex fractions in March, 1923. Conditions peculiar to Mexico that are absent, or seldom occur, in the United States are the main reasons for the insufficiency of published geological information on the oil fields. This historic sketch should prove of interest and value to all oil geologists and other members of the petroleum industry who are *en rapport* with conditions in Mexico.

JOHN M. MUIR

FORT WORTH, TEXAS
May 15, 1932

RECENT PUBLICATIONS

ARIZONA

Tentative Correlation of the Named Geologic Units of Arizona, compiled by M. Grace Wilmarth, secretary of Committee on Geologic Names (U. S. Geol. Survey, Washington, D. C., March, 1932). Chart, 23 × 28½ inches.

CANADA

"Oil and Gas in Eastern Canada," by G. S. Hume *et al*. *Geol. Survey of Canada, Econ. Geol. Ser. 9* (Ottawa, 1932).

GERMANY

"Ist Unterfranken erdölhöffig?" (Is Franconia Oil-Bearing?), by A. Bentz. *Petrol. Zeits.* (Berlin), Vol. 27, No. 18 (May 4, 1932), pp. 1-10; 6 figs.

KANSAS

"The Geology of Wallace County, Kansas," by M. K. Elias. *State Geol. Survey Bull. 18* (Lawrence, Kansas, 1932). 254 pp., 7 figs., 42 pls. Price (mailing charge), $0.25.

"The Fauna of the Drum Limestone of Kansas and Western Missouri," by Albert Nelson Sayre. *State Geol. Survey Bull. 17* (Lawrence, 1931). 129 pp., 21 pls. Price (mailing charge), $0.20.

MISSISSIPPI

U. S. Geol. Survey Bull. 831-A (Supt. Pub. Doc., Washington, D. C., 1932). Description of gas and geology of Jackson gas field, Mississippi. Price, $0.10.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 6 (JUNE, 1932), PP. 619-622

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Carl C. Anderson, Amarillo, Tex.
L. R. Hagy, J. D. Thompson, Jr., J. V. Terrill

Evert Willem Karel Andrau, Houston, Tex.
Alexander Deussen, L. P. Teas, P. L. Vaudoit

William Garland Talbott, Oklahoma City, Okla.
L. B. Snider, James FitzGerald, Jr., R. C. Quiett

FOR ASSOCIATE MEMBERSHIP

Arthur C. Munyan, Ashland, Ky.
C. D. Hunter, William O. Ziebold, J. E. Billingsley

Walter Vernon Searight, Vermillion, S. Dak.
Earl T. Apfel, Max Littlefield, E. P. Rothrock

FOR TRANSFER TO ACTIVE MEMBERSHIP

Robert B. Cheney, Tyler, Tex.
F. H. Schouten, A. C. Wright, O. L. Brace

Ward Rollin Vickery, Wichita, Kan.
Anthony Folger, Walter A. Ver Wiebe, Robert B. Dunlevy

COMMITTEE ON GEOLOGIC NAMES AND CORRELATIONS

This committee, appointed by past-president Garrett, consists of M. G. Cheney, chairman, Ira H. Cram, secretary, A. I. Levorsen, G. D. Hanna, R. C. Moore, C. L. Moody, and B. F. Hake. M. G. Cheney, R. C. Moore, and A. I. Levorsen will represent the Association on the National Committee of Stratigraphic Nomenclature, which will meet at the Boston meeting of the Geological Society of America in December, 1932.

The purpose of this committee has been clearly outlined by president Lahee as follows.

> The duties of this committee will be to serve in an advisory capacity with reference to new names proposed by Association members or proposed in papers for publication by the Association, or with reference to new uses of old names; and with

reference to problems of correlation. Each member will be asked to assist in this capacity in his particular region; and while he can not be expected to be familiar with all problems that may arise, or to check over questions in the field himself, he should be able to put proponents of new names in touch with persons who are familiar with the problems in hand or with the region which may be under discussion. In other words, this committee should be of real help to our members who are interested in studies of surface and subsurface correlation, and in this capacity the committee will be contributing a worthy service to the Association.

The committee is now working on a set of rules and procedure by which it will be governed. Further notice of the activities of the committee will be published in the near future.

IRA H. CRAM, *secretary*

TULSA, OKLAHOMA
May 16, 1932

DIVISION OF GEOLOGY AND GEOGRAPHY, NATIONAL RESEARCH COUNCIL

The Association is represented in the Division of Geology and Geography of the National Research Council by two members, one of whom (Sidney Powers) attended the annual meeting, held in Washington, April 23, 1932, and will serve on the executive committee of the division for the year commencing July 1.

President Lincoln created the National Academy of Sciences in 1863 and the charter was passed by the Congress of the United States to aid the government in "any subject of science or art," and, more particularly, in scientific problems connected with the Civil War. In 1916 President Wilson requested the Academy to create the National Research Council to coöperate with various departments of the government in studying and solving the scientific problems connected with the World War. The organization was confirmed by an executive order dated May 11, 1918. Both organizations are financed wholly by private funds and are housed in a beautiful building near the Lincoln Memorial built by a grant from the Carnegie Corporation. Several scientific exhibits of current interest, open to the public, are housed on the first floor.

The National Research Council has officers and an executive board, four divisions of General Relations, seven divisions of Science and Technology. The members of the latter divisions represent scientific and technical societies. Committees conduct or promote the research work and the membership of these committees is drawn both from within and without the membership of the division. There were 26 committees of the Division of Geology and Geography in 1931-32.

At the annual meeting the division chairman (Professor W. H. Twenhofel, 1931-32 and 1932-33) summarizes the work of the division for the year, and the chairmen of committees present reports of progress in special fields (Tectonics, Studies in Petroleum Geology, Sedimentation, Conservation of the Scientific Results of Drilling, et cetera) or on specific problems which have been studied by members of a committee (Shoreline Investigations, Atlantic and Gulf Coasts, et cetera).

The principal function of the Council is to promote and facilitate research and to act as a clearing house for new scientific facts and for compilations of scientific and technical data. Two series of publications are maintained, one called Bulletins, the other, Reprints and Circulars. Anyone desiring to know what recent progress has been made in a particular field can obtain assistance by writing the secretary.

Since the organization of the Committee on Grants-in-Aid in 1929 that committee has awarded for research in geologic or geographic projects $33,652.50, this amount going to 41 grantees in 49 grants. Since 1930 the division has had at its disposal a fund known as the Storrow fellowship fund, from which several fellowships have been annually awarded to graduate students. One of the most important of the division projects is the *Annotated Bibliography of Economic Geology*, sponsored by Professor W. Lindgren and published semi-annually by the Economic Geology Publishing Company, of Urbana, Illinois. Another project which serves geologists throughout the world is the *Treatise on Sedimentation*, by Professor W. H. Twenhofel and collaborators, published by Williams and Wilkins Company, of Baltimore, Maryland. A revised edition of 1,012 pages will appear in September. Owing to the generosity of Professor Twenhofel the royalties from the sale of this volume accrue to the Committee on Sedimentation for use in furthering research work, as do also the proceeds from the sale of the Color Charts, a project of the committee. Among other projects sponsored or supported by the division have been: Study of the Cromwell Oil Field, Oklahoma, to determine the origin of the anticlinal fold, financed by James H. Gardner; Geologic Map of Oklahoma, financed in part by $2,543.58 transferred by the council to the U. S. Geological Survey from the $3,434.18 collected from geologists in the Mid-Continent; Tectonic Map of the United States now in process of compilation by the Committee on Tectonics; and Catalogue of Latin American Maps, being published in four volumes by the American Geographical Society, of New York City.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 6 (JUNE, 1932), PP. 623-624

Memorial

J. CLAUDE JONES

In the death of Dr. J. Claude Jones on March 2, 1932, the University of Nevada lost one of the best beloved and most outstanding members of its faculty and the geologic profession an earnest worker of great enthusiasm for the advancement of knowledge. An old injury received in a game of soccer football, to which he was devoted when he went to the University of Nevada more than twenty years ago, brought on new trouble and necessitated a major operation. This apparently gave relief and he was showing rapid improvement when a clot in the blood stream unexpectedly proved fatal. Most lamentably he was thus stricken in his prime when, as the new dean of men, his value to the University and the community was greatest, and when richest fruits were to be expected from his broad familiarity with the geology of Nevada, acquired through many years of patient work.

J. Claude Jones was born on July 2, 1877, at Merrimac, Wisconsin, where he lived till eleven years old. The family moving to Chicago, he attended the Chicago Manual Training School, the first high school of its kind, and later entered the University of Illinois, graduating in 1902. From 1904 to 1906 he served the State University as assistant and instructor in geology and in 1906-1909 pursued graduate studies at the University of Chicago, spending the summers in field work for the Illinois Geological Survey. During these formative days at Chicago Jones was the recognized leader in the activities of the graduate students of the geological department, presiding at their meetings, toastmaster when such was needed, and universally liked for sterling personal qualities, contagious optimism, and general helpfulness. Later he received the degree of Ph. D. In 1909 he went to the University of Nevada as instructor in geology and mineralogy and was advanced to assistant professorship the following year. Full professorship and headship of the department in the Mackay School of Mines came in 1914.

Dr. Jones' scientific contributions were largely on the geology of Nevada. From careful studies of the tufa deposits of Lake Lahontan he concluded that this great lake had its beginning only 2,000-4,000 years ago and reached its greatest extent and depth only about 1,000 years ago. This was startling to not a few geologists in view of the fact that many of the large animals whose remains are found in these lake sediments are extinct or no longer live in the region. But he maintained his position against opposition, and more recent finds elsewhere by vertebrate paleontologists are now pointing strongly to the conclusion that many of the mammals no longer living in our western states continued to exist there much longer than formerly supposed, thus supporting Jones' contentions.

His studies on the origin of the tufa deposits in Pyramid Lake and the Salton Sea, as well as the origin of the oölites, were important contributions.

Various ore deposits occupied his attention from time to time and were described with his usual care and insight. But quite apart from his own researches he did a great amount of useful consulting work for which he received only modest compensation and little recognition. In fact, in his characteristic helpful spirit, he actually did much of the work which would naturally fall to a state geologist had there been an established State Survey, and truly is entitled to vastly more credit than he will ever receive.

In the upper 300 feet of the Lake Lahontan sediments, laid down in strongly saline water, Jones found petroliferous material from decomposing algae, whereas the deeper sediments, which accumulated before the lake became very salty, included oil shales but no petroleum.[1] The evidence afforded by the Lahontan basin led Jones to conclude that the chief difference in origin of oil shales and of sediments giving rise to petroleum lies in the degree of bacterial decomposition of the organic matter which, in turn, depends on the saline content of the waters in which the decay takes place. In the Lahontan basin the critical salt content seemed to be in the neighborhood of 2,500-3,000 parts per million.

Jones was elected to full membership in The American Association of Petroleum Geologists, February 15, 1923. He had worked with the United States Geological Survey; was a fellow of the Geological Society of America; was a member of the American Instutite of Mining and Metallurgical Engineers, the Seismological Society, American Association for the Advancement of Science, Sigma Xi, Phi Kappa Phi, and Sigma Gamma Epsilon. He is survived by a devoted wife who was Miss Belle McCurdy of St. Helena, California; two daughters, Mrs. Alberta McVarish of Empire, Colorado, and Dorothy Jones of Reno; a son, Dorence Jones, and a sister, Miss Mabel A. Jones of Chicago.

The numerous beautiful and heartfelt tributes expressed by those with whom and for whom he lived and worked reflect the strong personal affection so generally felt for the man and a grateful appreciation of his many kindly acts and valued services unostentatiously performed. He was devoted to his geology, his university, and his state and lived an unselfish life in the highest sense.

ROLLIN T. CHAMBERLIN

CHICAGO, ILLINOIS
May 16, 1932

[1] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7, No. 1 (January-February, 1923), pp. 67-72.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 6 (JUNE, 1932), PP. 625-628

AT HOME AND ABROAD

EMPLOYMENT

The Association maintains an employment service at headquarters under the supervision of the business manager.

This service is available to members and associates who desire new positions and to companies and others who desire Association members and associates as employees. All requests and information are handled judiciously and gratuitously.

To make this service of maximum value, all members and associates in the Association are requested to coöperate by notifying the business manager of openings available.

DAVID DONOGHUE, consulting geologist, Fort Worth National Bank Building, is receiver for U. S. Oils, an E. L. Chapman enterprise, of Fort Worth, Texas.

R. S. McFARLAND has moved from Tulsa to Dallas to take charge of operations in that territory for the Seaboard Oil Company, having been elected vice-president of the Texas Seaboard Oil Company, a subsidiary. His office is at 2013 Tower Petroleum Building, Dallas, Texas.

E. DEGOLYER has moved his office to Suite 2703, 120 Broadway, New York City.

FRANK C. GREENE, consulting geologist of Tulsa, Oklahoma, is working for the Missouri Geological Survey in northwestern Missouri this summer.

KIRK BRYAN, associate professor in the department of geology and geography at Harvard University, has charge of the Harvard Field School in Geology, June 27 to August 6, in the Jemez Mountains of central New Mexico.

SILAS C. STATHERS, chief geologist for the Standard Oil Company of Louisiana, stationed the past fifteen years at Shreveport, Louisiana, has retired from the service of the company, and expects to spend several months with his father and brothers at Buckhannon, West Virginia. Stathers was in the employ of the Standard Oil Companies for twenty-five years, working in the East Indies, Roumania, and the United States. After graduating from the School of Civil Engineering of West Virginia University in 1895, he was employed in the engineering department of the South Penn Oil Company in 1897. He was chief geologist for the Romano-Americano Petroleum Company in 1914 and 1916 and chief geologist for the Standard Oil Company of Louisiana from 1917 to 1932. On his recommendation the Standard of Louisiana was the first company in the Shreveport district to add a paleontologist to the geological de-

partment. On May 11 Stathers was the honor guest at a banquet given by the Shreveport Geological Society, of which he is immediate past president. Mr. Stathers plans to return to Shreveport to reside.

The Sixth Annual Field Conference of the Kansas Geological Society will be held, August 28 to September 3. The Permo-Pennsylvanian of Kansas, Nebraska, and Missouri will be studied under the leadership of R. C. MOORE, state geologist of Kansas, assisted by G. E. CONDRA, state geologist of Nebraska, and H. A. BUEHLER, state geologist of Missouri. A pre-conference trip will be made to Lyons, Kansas, the largest salt mine in the world, on August 27. The conference proper will convene at Wichita, Kansas, and conclude at Omaha, Nebraska. The registration fee is $10.00. The field conference committee is composed of EDWARD A. KOESTER, 421 Fourth National Bank Building, Wichita, Kansas, RAYMOND A. WHORTON, and E. C. MONCRIEF.

J. BRIAN EBY, of Houston, Texas, is the author of "The Economic Relation of Geophysics to Geology on the Gulf Coast," which was presented before Section E, Geology and Geography, of the American Association for the Advancement of Science and is now printed in *Economic Geology* for May.

The Natural Gas Department of the American Gas Association held its convention at Tulsa, Oklahoma, May 9, 10, and 11.

The Production, Refining, and Marketing divisions of the American Petroleum Institute met at Tulsa, June 1, 2, and 3.

C. F. BOWEN, of New York City, has returned from a trip to South America.

C. E. VAN ORSTRAND published in *Physics*, March, 1932, "On the Correlation of Isogeothermal Surfaces with the Rock Strata."

T. P. CONNERS has moved from Meridian, Mississippi, where he was working for the Gulf Refining Company, to 2656 East Eighth Street, Kansas City, Missouri.

TOM MCGLOTHLIN, recently of the Gulf Refining Company at Meridian, Mississippi, has moved to 527 North Douglass Street, Shawnee, Oklahoma.

The Tulsa Geological Society presented the following program at Tulsa, May 16: discussion of Hackford's "Treatise on the Origin of Oil," by ROY L. GINTER; and a paper on "Base Replacement Studies on Oklahoma Shale: A Critique of the Taylor Hypothesis," by L. C. CASE.

Colorado geologists and members of the United States Geological Survey were on a field trip May 9-14 to discuss problems of Colorado stratigraphy.

An article, "Sketch of the Geology of Bolivia," by Edward W. Berry of Johns Hopkins University, is published in part in the *Pan-American Geologist* for May.

B. W. BLANPIED, geologist for the Gulf Refining Company of Louisiana, has been transferred from Meridian, Mississippi, to Shreveport, Louisiana.

B. G. MARTIN, formerly with the Gulf Refining Company, may be addressed at Healdton, Oklahoma.

C. MAX BAUER, instructor of geology at the University of Colorado, has been appointed naturalist at Yellowstone National Park.

The second Pennsylvania Petroleum and Gas Conference was held under the auspices of Pennsylvania State College on May 20 and 21. C. A. BONINE is head of the department of geology, petroleum and natural gas engineering of the college.

Preliminary advance copies of a new geological map of the state of Texas are available. The map is being prepared by the United States Geological Survey and the Bureau of Economic Geology of the University of Texas.

JOHN L. RICH, of the faculty of geology at the University of Cincinnati, has returned to his consulting practice at Ottawa, Kansas, for the summer.

DAVID WHITE, senior geologist of the United States Geological Survey and a member of the National Academy of Sciences, was recently the recipient of one of the Academy's principal awards, the Mary Clark Thompson gold medal for distinguished service in paleontology. This honor followed Dr. White's election to honorary membership in the Geological Society of Belgium.

IRA H. CRAM, Pure Oil Company, Tulsa, Oklahoma, has a paper entitled "The Rest Island Granite of Minnesota and Ontario" in the April-May, 1932, issue of *The Journal of Geology*.

C. R. MCCOLLOM, chief geologist for the Pacific Western Oil Company, has resigned his position to enter the independent consulting field with R. R. TEMPLETON, formerly vice-president of the same company.

HOWARD F. NASH has returned from Bandoeng, Java, and is now at Polson, Montana.

E. A. RITTER, chief geologist for the Cia. Mexicana de Petroleo "El Aguila" S. A., has returned from The Hague, Holland, and is located at Tampico, Tamps., Mexico, for the same company.

ROBERT M. BEATTY, formerly of 945 West Ninth Street, Erie, Pennsylvania, may now be addressed at Box 1746, Houston, Texas.

ALBERT S. CLINKSCALES has resigned as secretary of Hall and Briscoe, Inc., and Kessler Oil and Gas Company, and has moved his office to 804 Colcord Building, Oklahoma City, Oklahoma.

H. B. HILL, supervising engineer for the United States Bureau of Mines, is completing a report of the Richland Parish gas field of Louisiana.

RAYMOND E. HEITHECKER, engineer for the United States Bureau of Mines, is compiling a report on the Zwolle field of Sabine Parish, Louisiana.

JAMES A. TONG, who has returned to Maracaibo from field work in the state of Falcon, is preparing a general report on the petroleum geology of Venezuela. He is geologist for the Standard Oil Company of New York.

Who's Who in Venezuela will soon be published, presenting the status of the oil business in that country. Information may be obtained from C. C. McDermond, Apartado 331, Maracaibo, Venezuela.

The National Oil Scouts Association of America, in ninth annual convention at Houston, Texas, May 15, 16, and 17, elected the following officers: president, LLOYD MCGEE, Houston, Texas; first vice-president, CLAUD STRAHAN, Atlantic Oil Producing Company, Shreveport, Louisiana; second vice-president, JESS L. BULLARD, Shell Petroleum Corporation; chairman of executive committee, G. C. FRANCISCO, JR., Sun Oil Company; and secretary-treasurer, J. W. SELBY (re-elected), Shell Petroleum Corporation, Dallas, Texas. The program included talks by WALLACE E. PRATT on "Why is a Scout?"; FRED C. SEALEY on "Gulf Coast Production Problems;" W. W. SCOTT on "Conservation of Pressure at Sugarland;" and M. G. WOLF on "Process of Sulphur Mining."

The Journal of the Institution of Petroleum Technologists (London) for April, 1932, contains "Reports on the Progress of Naphthology, 1930-1931," including "Petroleum Geology," by JAMES ROMANES and "Oilfield Practice," by A. BEEBY THOMPSON.

EZEQUIEL ORDOÑEZ, of Mexico, D. F., has written a book *El Petroleo en Mexico.*

WATSON H. MONROE is the author of *United States Geological Survey Bulletin 831-A*, entitled "The Jackson Gas Field, Hinds and Rankin Counties, Mississippi.

At its April meeting, the National Research Council's Committee on Grants-in-Aid made grants for the support of individual research as follows: RALPH L. BELKNAP, assistant professor of geology, University of Michigan, the establishment and operation of a weather station on the west coast of Greenland; BRUCE L. CLARK, associate professor of paleontology and historical geology, University of California, the Tertiary faunas of sections of the southern part of the United States, and of selected localities in Europe; CHARLES E. DECKER, professor of paleontology, University of Oklahoma, the large graptolite fauna of the Viola limestone; and JOHN M. MUIR, Fort Worth, Texas, monograph on Mexican oil fields, and a general map of the surface geology of the Tampico embayment.

FREDERICK A. BUSH, head of the geological department of the Sinclair Oil and Gas Company, Tulsa, Oklahoma, has been made chief geologist for the Sinclair-Prarie Oil Company.